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AN INVESTIGATION OF THE EFFECTS OF A DISPERSING AGENT UPON THE PHYSICAL PROPERTIES OF A CONCRETE MIX

A THESIS

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In Partial Fulfillment

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Master of Science in Civil Engineering

By

Daniel Jay Rhoades

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AN INVESTIGATION OF THE EFFECTS OF A DISPERSING

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Approved: ______________________

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Date Approved by Chairman: August 4, 1956

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CHAPTER I

INTRODUCTION

The purpose of this program was to determine whether a thorough and detailed investigation of dispersion agents A and C conducted at a later date would be of economic value. The problem resolved itself into the following question: What effect does cement dispersion have on the physical properties of a concrete mix by reducing the most costly item, the cement? The solution of the problem was obtained by proportioning each concrete mixture to have a constant aggregate content and water-cement ratio, with the cement factor varying as made practicable by the paste reducing characteristics of the dispersion agents. This approach would permit a direct economic comparison of the cement reducing qualities of each dispersion agent tested and would permit comparison of the physical effects of dispersion agents upon the concrete for various decreasing cement factors.

For this purpose, the program was set up based on the procedure referred to above, using two dispersion agents, A and B, in the concentrations of 0.025, 0.05, 0.10, 0.15 and 0.25 percent by cement weight. Shortly thereafter, two more dispersion agents, C and D were included in the investigation.

The relation of cement dispersion to various aspects of concrete technology has been described in the available literature.[†] It seems desirable, however, to make this report more vivid by reviewing the

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[†] Bibliography

history, mechanism and effect of cement dispersion on the properties of concrete.

History

Application of the principle of dispersion to hydraulic cements has assumed considerable importance in the last ten years and has found widespread use in every phase of concrete construction. Although dispersion of a solid material in a liquid is not new, having been used extensively in the textile, chemical and related fields, the application to the concrete field has been very recent, approximately within the past twenty-five years.

The form of concrete dispersion that is used today was discovered in the early thirties by Scripture[1] and Mark[2]. They found that the lignin derivative from waste sulfate liquor (calcium lignosulfate) improved the workability of the concrete mix to such an extent that the water-cement ratio could be reduced and in accordance with the theory advanced by Duff A. Abrams in 1918[3], the resultant compressive strength was increased. However, during this era the refining process of the waste sulfate liquor was not as efficient as today, and enough sugar was left in the resultant product to increase the final setting time of the concrete, which decreased the compressive strength if an accelerator was not present. Therefore calcium chloride was added to the product in that quantity necessary to overcome the detrimental effects produced by the lack of an improper refining process. Since that time the use of concrete dispersion agents in millions of yards of concrete testifies to its wide acceptance and field performance. By now, dispersions of concrete has been established as a practical means of improving the physical properties of concrete and is readily accepted by Consulting Engineers and by Federal and State officials.

The Mechanisms of Concrete Dispersion

When cement or other fine-grained particles are mixed with some liquids, there is a tendency for the individual particles to stick together in small clusters or flocs. This is known as flocculation. By the addition of certain chemicals, the amount of flocculation may be lessened considerably (any chemical that is used to lessen flocculation is known as a dispersion agent). Ernsberger and France[4] explain this operation as follows: "Cement particles suspended in distilled water show no tendency to migrate toward either electrode; in fact, the particles agglomerate and settle out so rapidly it is difficult to find one which can be observed. On the other hand, cement particles suspended in calcium lignosulfate show a readily observable migration toward the anode. It may therefore be concluded that cement particles acquire a negative potential in calcium lignosulfate solution, leading to the formation of a more stable suspension. The negative potentials of the cement particles are attributable to the adsorption of lignosulfonate anions and the existence of such ions may be demonstrated by a simple electrophoresis experiment".

Another means of illustrating the action of cement dispersion may be found by mixing two solutions; one of plain cement and water and the other of cement and water with a dispersion agent added. The increased dispersion is apparent both from the vigorous Brownian motion[5†] present in

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†Brownian motion is a movement or vibration caused by unbalanced impacts of the molecules of the surrounding medium. If a particle is small enough and the forces of impact are not in equilibrium, the particle thus acquires motion.

the dispersed solution and from the increased time it takes the dispersed cement to settle out of solution.

The Effect of a Dispersion Agent

Dispersion of cement has several important aspects. Scripture[6] explains this as follows: "Dispersion of cement produces three important effects. The water which had been trapped within the particle clumps is released to become a part of the mixing or placing water. The surface area of the cement in contact with water is greatly increased, since the particles are no longer in contact with each other. A certain amount of air is entrained. As a result of the first, the amount of water required in the mix for a given consistency is less, i.e., the water-cement ratio is reduced. Since the value of the cement is dependent on a hydration reaction which is a surface phenomenon, the second effect promotes more efficient utilization of the cement. The additional air contributes to improvement in the properties of the concrete with respect particularly to bleeding and durability as is the case with air entraining agents. By the reduction in water-cement ratio and by the increase in surface area of cement available, the potential value of the cement is more completely realized".

Powers[7] contradicts Scripture by implying that a dispersion agent would be undesirable for three reasons. It may increase the rate and amount of sedimentation (bleeding) and promote segregation in cement paste; it would destroy the plasticity of the pastes and give them the properties of a fluid; it would have no beneficial effect on the rate of hydration during the early stages of hydration through increased surface area of the cement particles, since the surface area is usually exposed to water even when flocculated. However, Power's theory dealt with a pure dispersant with no air-entraining qualities and was not backed by conclusive data. Powers does admit that dispersion is beneficial if it contains admixtures to increase the air content. The use of dispersion in concrete increases the fattiness or cohesiveness[8] of a mix and with the additional entrainment of air, helps to increase the speed of construction by decreasing bleeding and thus the finishing time. Through the above mentioned improvements of the plastic mix the hardened concrete becomes stronger, less permeable, more resistant to sulfate action and to freezing and thawing. These effects are largely produced by the air entrainment and reduction in the water-cement ratio of the dispersed concrete.

In conclusion, the following effects are found to be produced by present dispersion agents on concrete.

Plastic Concrete

1. Reduced Unit Weight
2. Increased Air Content
3. Increased Cohesiveness of the Mix
4. Increased Plasticity With Less Water
5. Reduced Bleeding and Segregation
6. Reduced Shrinkage

Hardened Concrete

1. Increased Strength - Bond, Compressive, and Flexural - (depending on air content)
2. Increased Durability

3. Decreased Permeability and Increased Watertightness With Time

4. Increased Density

CHAPTER II

INSTRUMENTATION AND EQUIPMENT

All the equipment used in this investigation was that readily available in the State Highway Department and Georgia Institute of Technology Joint Research and Laboratory Building. The major items of equipment used in the program are listed below. These include:

Electro Sonometer and Oscillograph[9, 10, 11]

The Electro Sonometer consists of a Sonometer cabinet, a driver, a pickup and the necessary cables. The Sonometer cabinet houses the oscillator, the power or driver amplifier and the pickup amplifier. The oscillator is accurate to at least two percent over its entire frequency range (20 cycles - 20 kc) and for variations in line voltage from 105 to 125 volts.

The driver amplifier is a three stage, push-pull amplifier capable of delivering 18 watts of power to the driver over a range from 20 cycles to 15 kc.

The oscillator is coupled directly to the driver amplifier and this amplifier delivers power to the driver for operating the driver hammer. When the driving hammer is placed against one end of a concrete cylinder and the power is increased, a wave motion is induced that is dependent upon the force of the driving hammer.

The pickup is placed on the other end of the cylinder and in line with the longitudinal axis of the cylinder. The motion of the sample generates a voltage in the pickup. This voltage is passed on to the pickup amplifier which is used to operate the resonance indicator.

For phase comparisons, the driver voltage may be connected to the X axis terminals and the pickup voltage connected to the Y axis terminals of a 5 inch oscillograph. The frequency indicated on the oscillator dial when maximum deflection of the resonance indicator is obtained, is the resonant frequency of the first mode of flexural vibration if the phase relationships, as indicated by the oscillograph, are 360° out of phase. For a block diagram of this Sonometer system, see Figure 1.

Bond Test Equipment

All pull-out tests were performed on a 100,000 pound Olson Testing Machine using the testing apparatus as recommended by the ASTM Standards[12]. Slippage of the bar was measured at both the loaded end and at the free end of the number 6 reinforcing bar. The arrangement of the 0.0001 inch upper dial and the two lower 0.001 inch dials are shown in Figure 2. All dials were read to an estimated 0.1 of the least division of the dials, and loadings were continued until failure in bond or failure by cracking of the nine inch concrete cube.

The number 6 reinforcing steel met the following specifications as supplied by the manufacturer:

1.	Type and Deformation	Number 6 Deformed
2.	Average Height, Inches	0.045
3.	Spacing, Inches	0.31
4.	Total Gap, Inches	0.30
5.	Yield Point, Psi	50,000

6.	Tensile Strength, Psi	76,000
7.	Percent Elongation, 8"	22

Physical Properties of Concrete

Fine Aggregate	Crushed Lithonia Granite; FM = 2.70
Coarse Aggregate	Crushed Lithonia Granite 1" Maximum Size, FM = 7.00
Cement	Coosa, Type I Portland Cement

Admixtures

Physical and chemical properties of the admixtures are shown in Table 1.

Miscellaneous Equipment

All the equipment necessary to test the aggregate, cement, plastic concrete and hardened concrete, (except as previously noted), conform to 1955 ASTM Standards and their description is not included here since they may be found in the selected references.

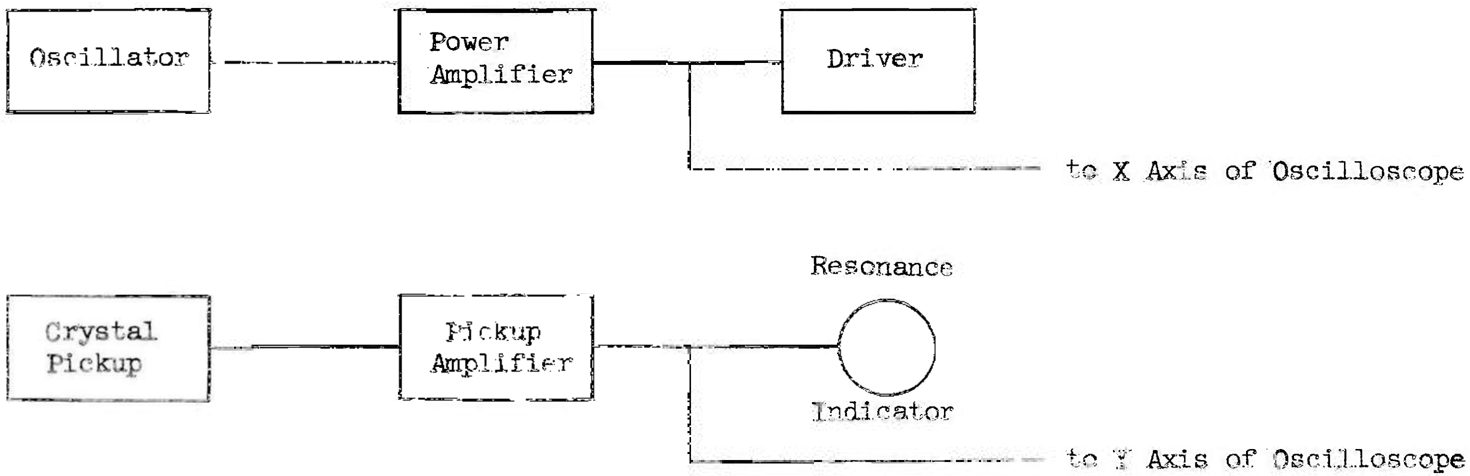


Figure 1. Electro Sonometer System

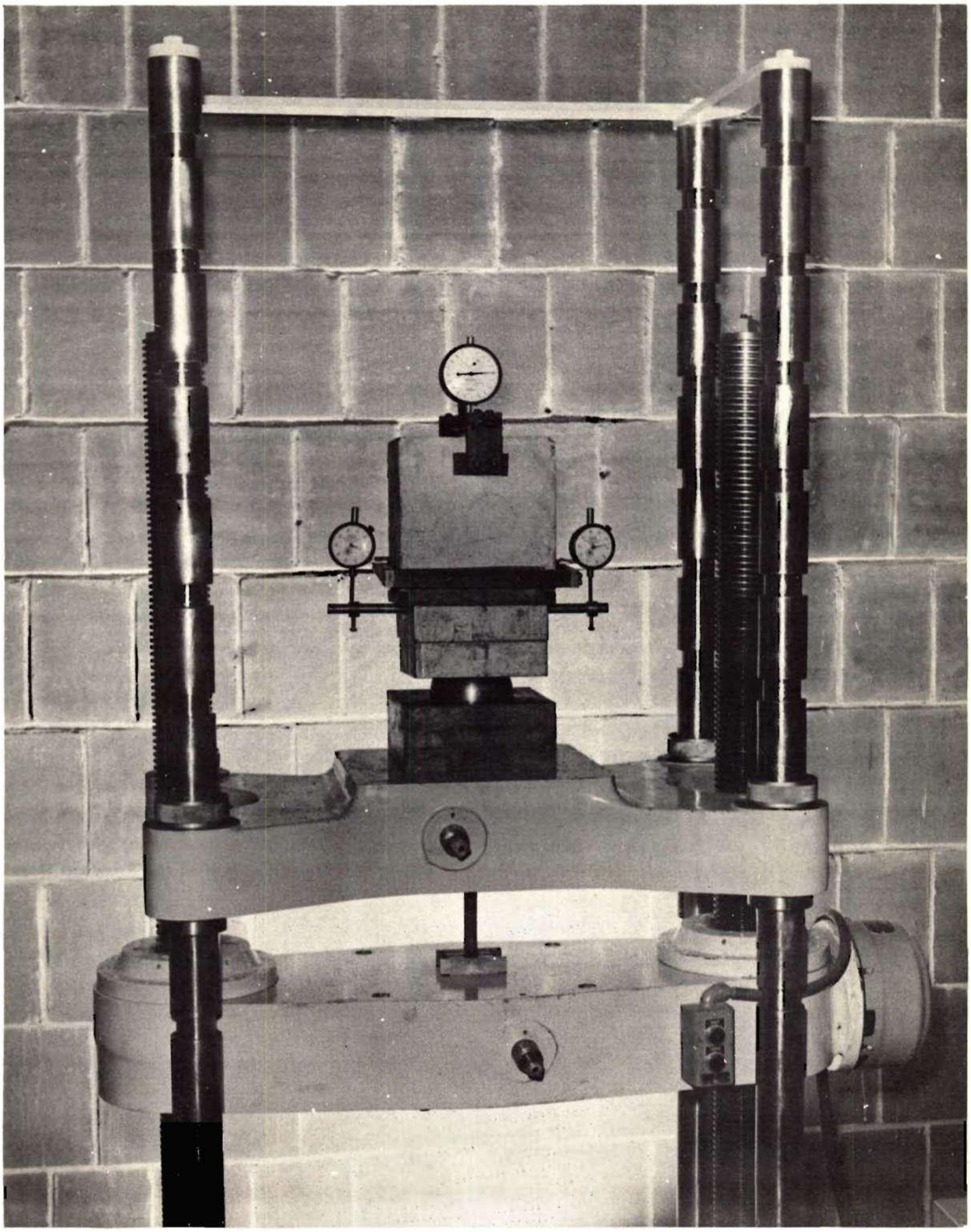


Figure 2. Bond Test Apparatus.

Table 1. Analysis of Admixtures

Admixtures	A	B	C	D
Characteristics				
Probable source	Paper pulp byproducts (acid process)			
Form	Powdered solid			
Color	Black	Tan	Deep Brown	Tan
Odor	Slightly pungent			
Qualitative Tests				
Solubility:				
In water	Soluble			
In alcohol, xylene, and chloroform	Insoluble			
Permanganate test	Reacts Rapidly			
Aqueous solution:				
Compatibility with dil. Hcl	Compatible			
Test for calcium	Absent	Present	Absent	Present
Test for sodium	Present	Present	Present	Absent
Test for potassium	Absent	Absent	Absent	Absent
Test for chloride	Present	Present	Absent	Present
Test for sulfate	Absent	Absent	Absent	Absent
Ash:				
Presence	Present	Present	Present	Present
Test for sulfate	Present	Present	Present	Present
Test for calcium	Absent	Present	Present	Present
Quantitative Determinations				
Water - Percent	12.4	8.3	11.5	5.4
Calcium chloride - [illegible]	[illegible]	[illegible].0	0.33	25.9
Calcium lignosulfona[illegible]	[illegible]	[illegible].7	88.2	68.7

†By difference

CHAPTER III

PROCEDURE

The procedure followed in this investigation was divided into four definite stages: preparation of aggregate, mixing the concrete, testing plastic concrete and testing hardened concrete.

Preparation of Aggregate

The Lithonia granite, which was to be used for both the coarse and fine aggregate, was tested to determine the physical properties necessary in concrete mix design[13] and the conformity to the specifications for concrete aggregates[14].

To eliminate as many variables as possible, the aggregate was air dried to a free flowing condition and then vibrated for fifteen minutes through a standard set of sieves in a Gilson mechanical testing screen. The individual aggregate gradations were stored in 32 gallon, sealed containers and during the concrete batching process were recombined by weight[15] in the amounts necessary for 1-1/2 cubic feet of concrete. Moisture content determinations were made previous to each mixing of the four admixtures and found to be relatively constant. The physical properties of the aggregate are shown in Table 19.

Mixing Concrete

Each mixture was designed to have a constant aggregate content and water-cement ratio with the cement factor varying as made practicable by the characteristics of the admixture to develop a nominal slump of 3 ± 1/2 inch. Trial batches were mixed for each admixture concentration to determine the cement and water content for the desired slump. The average size batch was 1-1/2 cubic feet in volume and was mixed in a 2-1/2 cubic foot tilting drum mixer. No mixing was done without first coating the inside of the mixer with a thin film of mortar that had the water-cement ratio of the reference mix. The charging sequence of the mixer was as follows:

1. Fine aggregate, coarse aggregate and cement
2. One half of the mixing water
3. Admixture
4. Remaining half of mixing water

Following the addition of the materials, including the water, all batches were mixed for two minutes, allowed to rest for three minutes and remixed for one minute.

All batches were discharged into a large metal pan, and no more than twenty minutes elapsed after the initial mixing before testing began. A maximum of three batches per admixture concentration was required for Group I, admixtures A and B, since bond test specimens were cast. Group II admixtures C and D, required two batches per admixture concentration. A reference concrete mix of identical proportions was cast with each group in order to compensate for any errors produced by the time differential of mixing Groups I and II. The individual admixture concentrations were dependent on the cement content and consisted of: 0.025, 0.05, 0.10, 0.15 and 0.25 percent by cement weight. The reference concrete mix proportions are shown in Table 21.

Testing Plastic Concrete

The entire plastic concrete for each admixture concentration was mixed with a concrete shovel to a uniform consistency for one half minute before performing the identification tests. A slump test[16] was performed twice on each 1-1/2 cubic foot batch and each total batch to insure uniform results.

The molding of all specimens was accomplished by rigid adherence to standard practices and each operation was performed insofar as practicable by the same person throughout the testing program. The types of tests performed and specimens cast for each admixture concentration were:

(a) Unit weight[17]

(b) Bleeding[18] - temperature controlled for admixtures C and D

(c) Air content[19] average of three readings

(d) Cylinders[20] nine cylinders cast for testing at 3, 7, and 28 days. Each cylinder was stripped at twenty hours and cured in fog at $70^{\circ} \pm 2^{\circ}F$ until time of test

(e) Bond test cubes[21] - two vertical, two horizontal with 4.5 inch concrete cover and two horizontal with 13.5 inch concrete cover. Each cube was stripped at twenty hours and cured in fog at $70^{\circ} \pm 2^{\circ}F$ until time of test at 28 days. (Group I only)

The plastic concrete analysis is shown in Table 8. A summary of tests performed is shown in Table 22.

Testing Hardened Concrete

The 6 x 12 inch concrete cylinders were removed from the curing room three hours before compression testing, and the accumulated surface moisture was removed from the cylinders with a soft cloth previous to the sonic determinations. The weight and length of the cylinders were determined within ± 0.5 percent and the average cross-sectional dimensions were determined within ± 1.0 percent. Each cylinder was then placed on knife supports located approximately 2.6 inches from the cylinder ends and accurately positioned with a metal rule. The driving force was placed normal to the surface and at one end of the cylinder. The pickup unit was positioned against the other end of the cylinder and in line with the long dimension of the cylinder. The driving power was then increased until a maximum reading was obtained on the resonance indicator. The frequency obtained at this point is the resonant frequency of the first mode of flexural vibration if the phase relationship of the driver voltage and the pickup voltage are 360 degrees out of phase as indicated by the oscillograph in Figure 3. This frequency, N, is the value used in determining Young's Modulus of Elasticity[22] by means of the formula:

$$E = CWN^2$$

Where:

E = Young's modulus

W = Weight of specimen in pounds

N = The resonant frequency in cycles per second

C = A factor which depends upon the shape and size of specimen, the mode of vibration and Poisson's ratio.

All cylinders were capped within one hour after the sonic determination and were replaced in the curing room for two hours before testing. The cylinders were tested on a 450,000 pound Riehle testing machine which was read to the nearest 100 pounds.

The horizontal bond test specimens were removed from the curing room and broken in flexure at twelve days. Care was taken not to disturb the rods during this operation. At twenty-eight days the specimens were removed from the curing room and tested for bond strength.

The loading rate during the bond test was continuous at a rate not greater than 5000 pounds per minute, with all dials being read and recorded to an estimated 0.1 of the least division of the dial. Readings were taken in the following increments:

0-5000 pounds, 250 pound increments

5000-9000 pounds, 500 pound increments

9000-ultimate load-1000 pound increments

The type of failure was noted and recorded in Tables 16 - 18.

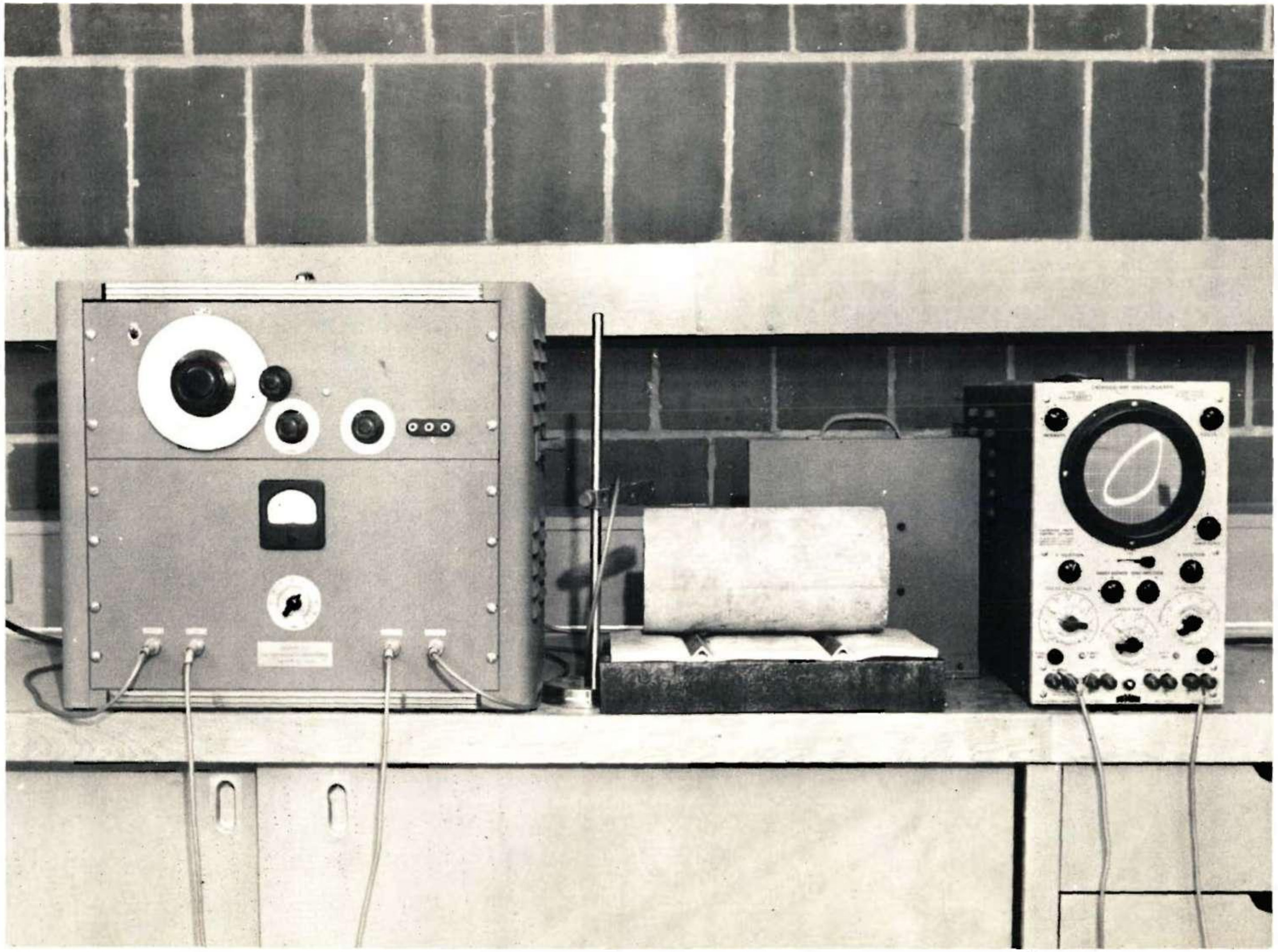


Figure 3. Electro Sonometer.

CHAPTER IV

DISCUSSION OF RESULTS

All concrete was made using Type I Coosa Cement, tap water at approximately 70°F and Lithonia granite. The admixtures used were primarily calcium lignosulfonates with admixtures B and D containing 29 and 25.9 percent calcium chloride. Admixtures A and C contained only a trace of calcium chloride. Tables 1, 19 and 20 list the physical properties of all materials.

Plastic Concrete Analysis

The plastic concrete results are recorded in tabular form in Table 2 and in graphic form in Figures 4 - 8. All test points were plotted and the best average curve was drawn, shown as a solid line. The data from which the information was obtained is included in Tables 5 - 9.

Slump

The mixtures were proportioned for 3 ± 1/2 inch slump. Actual slumps are listed in Table 8. All mixes were workable with the cohesiveness increasing with admixture concentration.

Bleeding

The large reduction in bleeding developed by the mixtures containing admixtures A and C is evident in Table 2 and Figures 4-7. In general, admixtures A and C decreased bleeding while admixtures B and D increased bleeding. As discussed in Chapter I, a dispersion agent reduces bleeding more efficiently if air is entrained. However, this statement applies mainly to a dispersed concrete mix that has a lower water-cement ratio than the reference mix. Since bleeding is also a direct function of the water present there should be little change in bleeding rates for equal water-cement ratios and consistency; except for that which may be effected by reduced paste content or increased hydration from the effect of calcium chloride. The reduction in cement factor[23], without a substantial increase in air content, produced a decrease in surface area of the mix in relation to water present which would account for the increased bleeding rate for admixtures B and C.

The apparent inconsistency in the bleeding percent for reference mixes 0-0 and 0-1, as listed in Table 2, was produced by the difference in bleeding temperature and the effect caused by using a newer cement. Cement may vary in quality if obtained from batches of different fineness or of different ages. Since admixtures C and D were tested after admixtures A and B, it was necessary to purchase a new supply of fresh cement. The time limitation would not permit the testing of the cement, so a new concrete reference mixture was made.

Unit Weight

Admixtures A and C produced a greater decrease in unit weight than admixtures B and D, largely because of the greater amount of air present in the plastic concrete.

Air Content

As shown in Table 2, admixtures A and C increased the air 135 and 197 percent greater than admixtures B and D. It appears from an inspection of Figure 8, that the amount of air which will be entrained in a given concrete mixture with a given amount of an air entraining admixture can be determined accurately only by tests using the concrete and admixture involved. It should also be noted that admixture concentration and air content is practically a linear relationship for all admixtures.

As a check of the pressure method of determining air content, the air content was calculated from properties of the individual mixes. Results are consistent as listed in Table 9. This table indicates accurate measurement by the pressure method. A small error in specific gravity or significant figure in the calculations would account for the difference.

Cement Content - Lbs, Cement Factor - Bags/Cy and Yield

The data listed in Table 2 indicates a large reduction in cement content for both admixtures A and C which was produced by the dispersion effect and greater air content with a resultant increase in workability. Yield was necessarily increased since the cement factor was reduced. The largest saving in cement for equal consistencies is as follows:

Admixture	Strength Ratio Percent	Cement Reduction Lbs	Cement Saving Over Reference Mix Percent
A-5	90	71	13.70
C-5	86	60	11.60
B-5	99	32	6.20
D-5	110	14	2.71

Water Content

As shown in Table 2, the water content is reduced to a greater extent in admixtures A and C due to their greater ability to increase the consistency of concrete. As discussed in Chapter I and in previous paragraphs, this increased consistency results from increased air content and dispersion effect.

Hardened Concrete

The hardened concrete results are recorded in tabular form in Tables 3 and 4 and in graphic form in Figures 9 - 16. The data from which the information was obtained is included in the Appendix in Tables 10 - 18.

Compressive Strength

The influence of the various admixtures in their respective concentrations is shown in Table 3 and in Figures 8 - 12. Admixtures B and D show the greatest percent increase in strengths for all ages which should be expected from the calcium chloride content, higher cement factor and low air content. Admixture D shows the most uniform increase in 28 day strength and attains a maximum strength of 110 percent of the reference mix. However, it must be remembered that this mix has only 3.4 percent air and 2.71 percent decrease in cement content. Admixture D would compare with the other admixture in respect to air content as follows:

Admixture	Air	Decrease in Cement Content - Percent	Ratio of Compressive Strength - Percent
A-4	3.50	8.71	95
B-5	3.10	6.20	99
C-2	3.15	2.13	99
D-5	3.40	2.71	110

Notice that even without the accelerator and with a much lower cement content A-4 has a strength ratio of 95; whereas B-5, at a stronger concentration, with a higher cement factor and with an accelerator present, shows a strength ratio of only 99. Admixture C declines with reduced cement factor and increased air content as should be expected but at a more consistent rate than the other admixtures. The difference in compressive strength for the reference mixes is attributed to the cement as previously discussed.

In the classification of air entraining admixtures for the Bureau of Public Roads[24], the following criteria was used as acceptance: "When the admixture is used in an amount sufficient to entrain between 3 and 6 percent air in concrete of the proportions normally used for pavements and bridges:

1. The flexural and compressive strength of the concrete at the ages of 3 days, 28 days and 1 year shall not be less than 88 percent of the strength of similar concrete of the same cement content and consistency but without the admixtures."

Using the 88 percent strength criteria as concerning only the 3 and 28 day compressive strength, all admixtures would be acceptable as shown in Table 3.

Sonic Modulus

The sonic modulus results, as shown in Table 3 and in Figures 13 - 16, generally decrease with entrained air. Any variation in results may be due to reading the frequency as determined in the testing procedure or in moisture content variation. There is a trend toward close agreement between the modulus of elasticity-percent ratio and the compressive strength-percent ratios, as should be expected.

Bond Strength

The effects of admixtures (A and B only) on the bond of concrete to steel are shown in Table 4. The deviation in results is partially explained in Tables 16, 17 and 18 where notation is made of water leakage at the point of entrance of steel and concrete. This would produce weaker bond strength, since the cement paste needed for bond strength had been altered during the bleeding process beneath the reinforcing steel. In several instances the reinforcing rods were out of plumb, which would produce unbalanced stress on the cement cube during testing.

Discounting the above mentioned defects, Table 4 indicates that bond stress is affected by increased air content and reinforcing steel position. In general, the bond was strongest for concrete of 13.5 inch cover and steel placed horizontally. Admixture B was more consistent with results at ultimate load, as should be expected from the accelerator present and the lower air entrainment. However, it appears that excessive bleeding caused a consistent loss in bond strength for admixture B at the first recorded slip of 0.001 inch, measured at the free end.

Table 2. Admixture Summary Sheet

Admix-ture	Unit Wt Pcf	Unit Wt Reduc-tion Pcf	Bleed-ing Per-cent	Ratio Per-cent	Air Content Per-cent	Per-cent In-crease	Cement Content Lbs	Per-cent De-crease	Water Content Lbs	Per-cent De-crease	Yield Ft^3/ Bag	Per-cent In-crease	Cement Factor	Per-cent De-crease
0-0	146.50	0.00	9.44	100	2.15	0.00	517	0.00	337	0.00	4.88	0.00	5.52	0.00
A-1	146.40	0.10	9.42	100	2.20	2.32	517	0.00	337	0.00	4.88	0.00	5.52	0.00
A-2	146.40	0.10	8.52	90	2.30	6.95	506	2.13	330	2.07	5.00	2.46	5.40	2.17
A-3	146.00	0.50	8.36	89	3.00	39.53	495	4.26	323	4.15	5.07	3.89	5.34	3.26
A-4	145.60	0.90	8.34	88	3.50	62.79	472	8.71	309	8.31	5.28	8.19	5.12	7.25
A-5	142.20	4.30	8.05	85	6.00	179.07	446	13.70	293	13.06	5.64	15.50	4.79	13.20
B-1	146.48	0.02	8.90	94	2.50	16.28	513	0.78	334	0.89	4.89	0.20	5.52	0.00
B-2	146.40	0.10	10.59	112	2.65	23.26	504	2.52	329	2.36	4.97	1.84	5.44	1.44
B-3	146.40	0.10	10.95	116	2.70	25.58	489	5.42	320	5.05	5.10	4.50	5.30	3.99
B-4	146.20	0.30	10.95	116	2.80	30.23	487	5.81	318	5.64	5.12	4.91	5.27	4.53
B-5	145.40	1.10	11.32	120	3.10	44.19	485	6.20	316	6.22	5.15	5.53	5.24	5.07
0-1	146.25	0.00	7.13	100	2.15	0.00	517	0.00	337	0.00	4.88	0.00	5.52	0.00
C-1	146.20	0.05	7.12	100	2.65	23.26	515	0.39	336	0.30	4.90	0.41	5.52	0.00
C-2	145.75	0.50	5.50	77	3.15	49.30	506	2.13	331	1.78	4.98	2.04	5.42	1.81
C-3	143.70	2.55	5.56	78	4.40	104.65	496	4.06	324	3.86	5.15	5.53	5.24	5.07
C-4	140.79	5.48	5.80	81	5.60	160.46	477	7.75	312	7.42	5.40	10.06	5.00	9.40
C-5	139.86	6.39	6.03	85	7.80	253.49	457	11.60	300	10.95	5.64	15.50	4.79	13.20
D-1	145.99	0.26	8.32	117	2.25	4.65	516	0.19	336	0.30	4.91	0.61	5.50	0.36
D-2	145.70	0.55	8.50	119	2.45	13.94	513	0.78	335	0.59	4.93	1.02	5.48	0.73
D-3	145.00	1.25	9.71	136	2.70	25.60	509	1.54	332	1.48	4.97	1.84	5.44	1.44
D-4	144.70	1.55	11.19	157	2.95	37.20	508	1.74	332	1.48	5.00	2.46	5.40	2.17
D-5	143.62	2.63	11.35	159	3.40	58.14	503	2.71	329	2.37	5.10	4.50	5.30	3.99

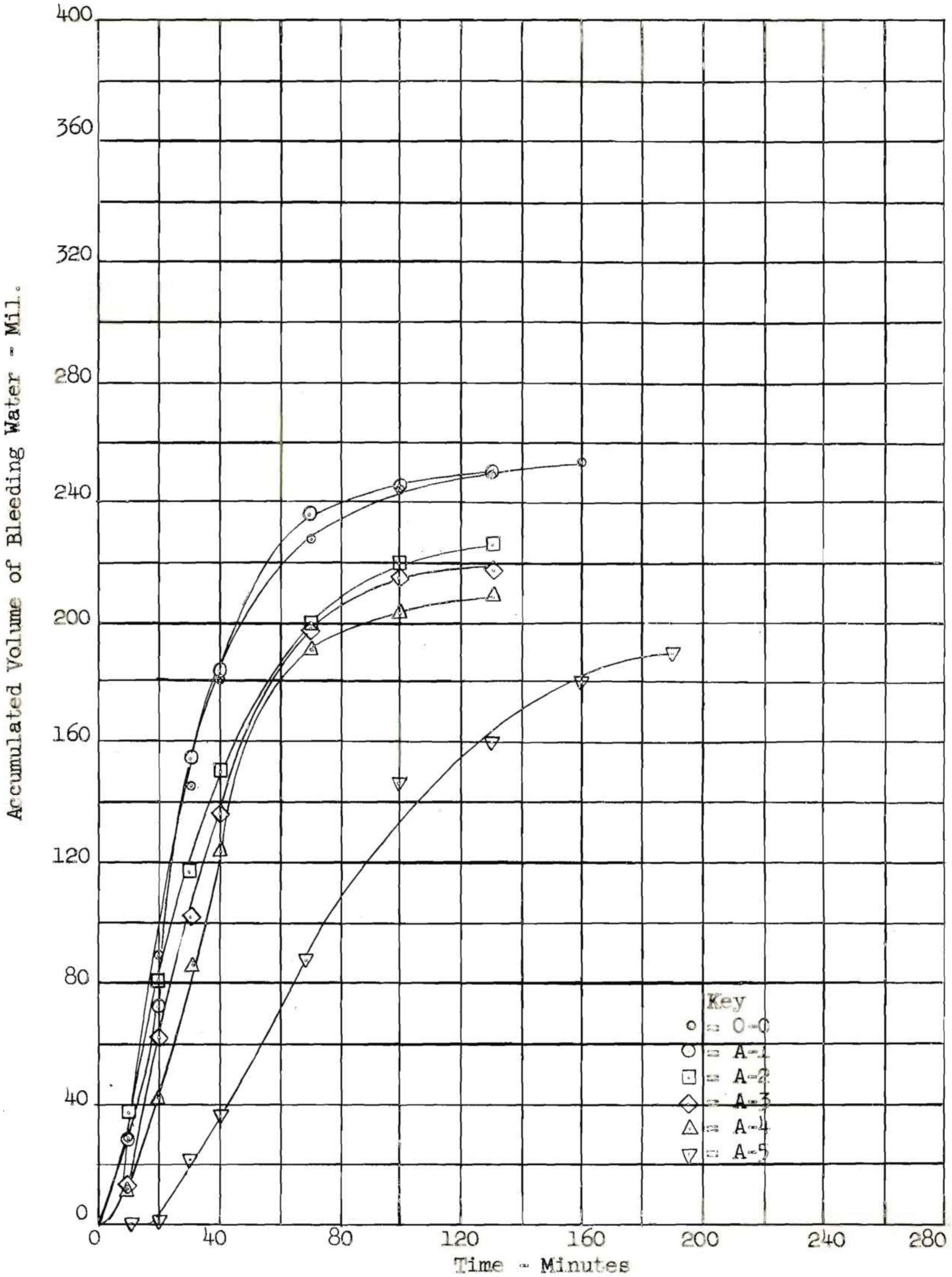


Figure 4. Admixture A Accumulative Bleeding
Vs Time

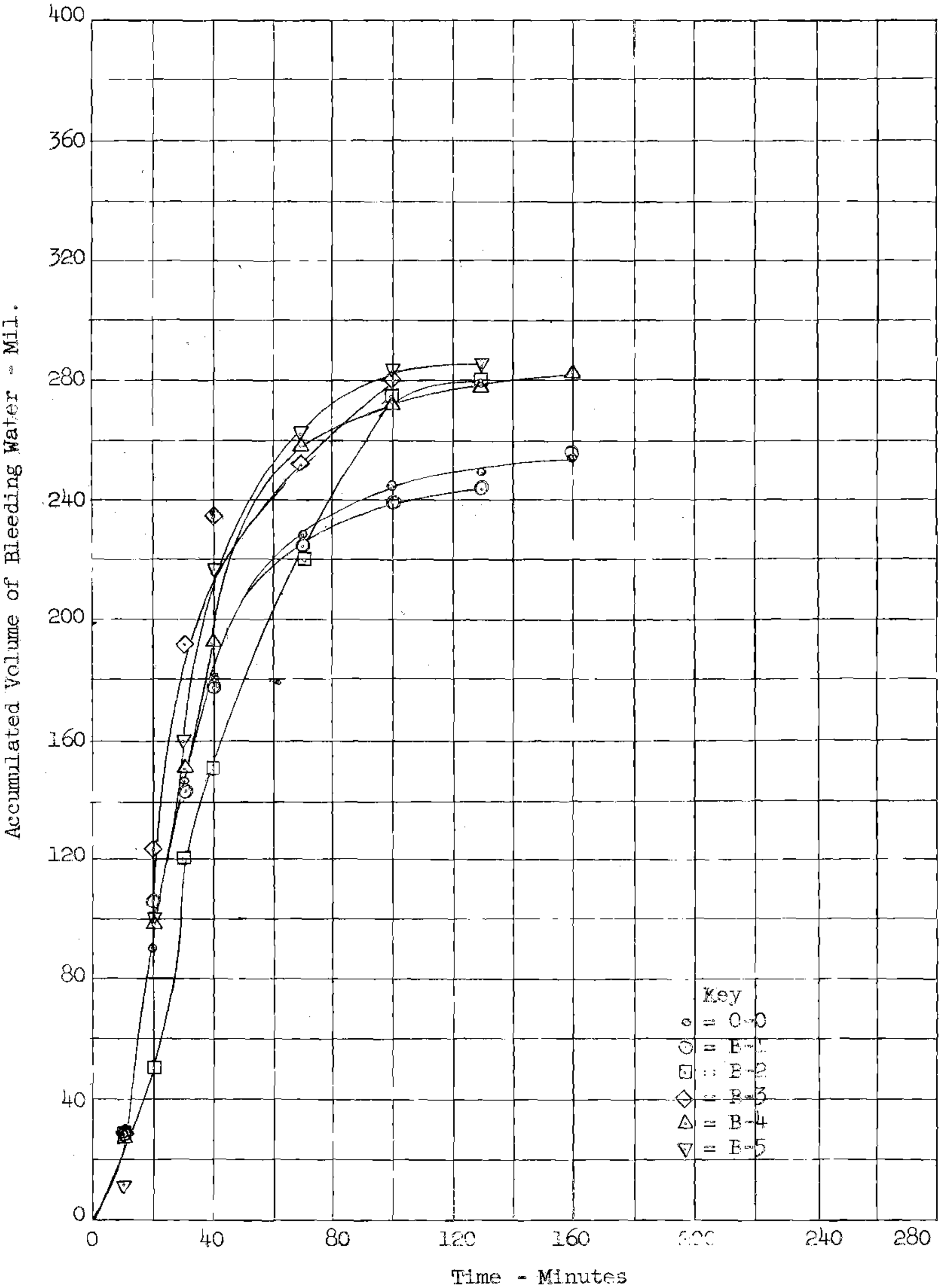


Figure 5. Admixture B Accumulative Bleeding Vs Time

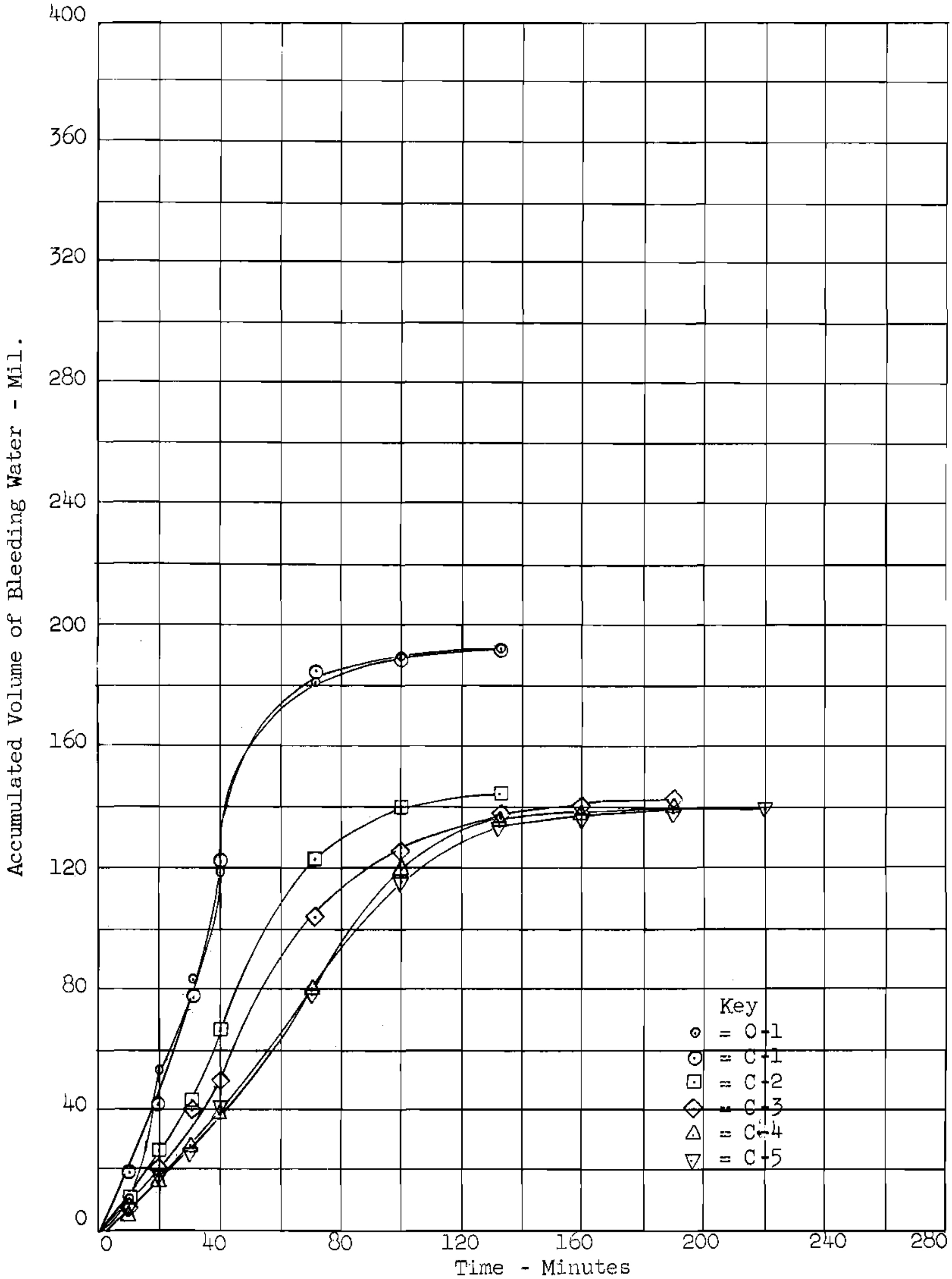


Figure 6. Admixture C Accumulative Bleeding Vs Time

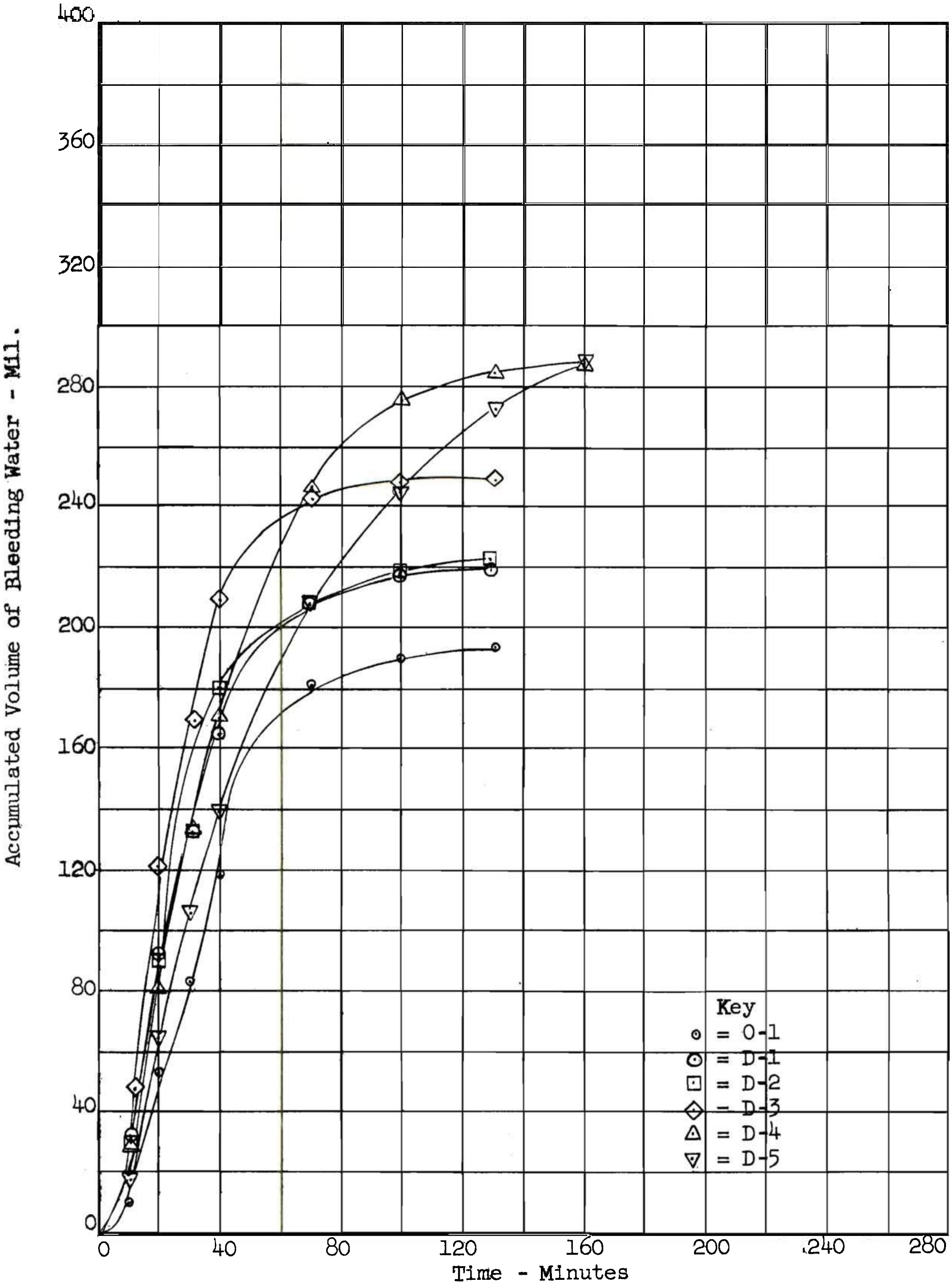


Figure 7. Admixture D Accumulative Bleeding Vs Time

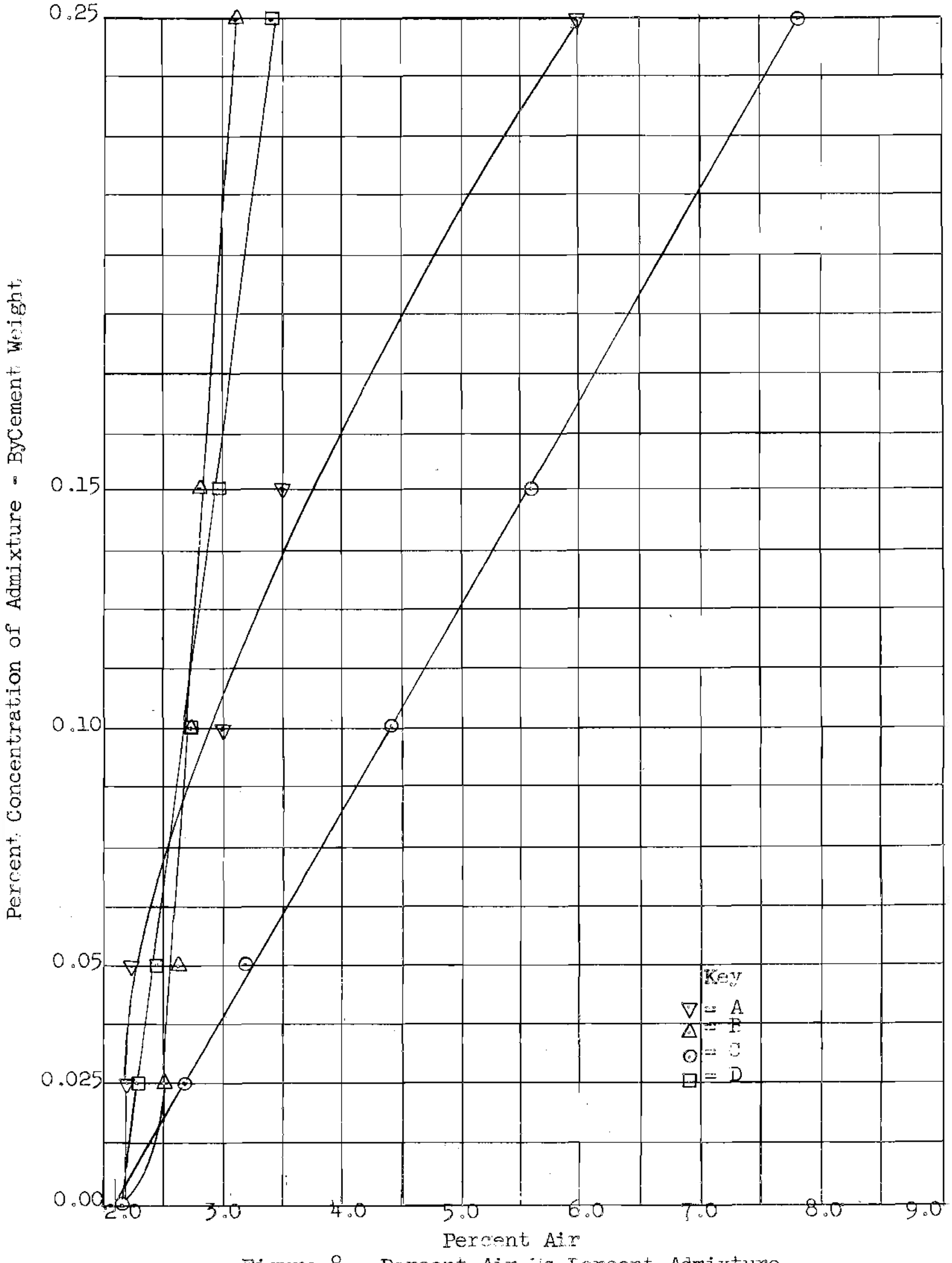


Figure 8. Percent Air Vs Percent Admixture

Table 3. Admixture Summary Sheet

Admix-ture	Compressive Strength						Dynamic Strength					
	3 Days		7 Days		28 Days		3 Days		7 Days		28 Days	
	Strength Psi	Ratio Percent	Strength Psi	Ratio Percent	Strength Psi	Ratio Percent	$E \times 10^6$ Psi	Ratio Percent	$E \times 10^6$ Psi	Ratio Percent	$E \times 10^6$ Psi	Ratio Percent
0-0	1647	100	2290	100	3663	100	3.01	100	3.32	100	4.35	100
A-1	1632	99	2530	110	4183	114	3.06	102	3.34	101	4.43	102
A-2	1740	106	2673	116	4000	109	3.10	103	3.38	102	4.24	98
A-3	1610	98	2340	102	3693	101	3.09	103	3.43	103	4.13	95
A-4	1570	95	2370	104	3480	95	3.09	103	3.44	104	4.06	94
A-5	1438	87	2240	98	3317	90	2.92	97	3.37	102	4.04	93
B-1	1660	101	2627	115	3757	102	3.08	102	3.46	104	4.31	99
B-2	1670	101	2613	114	3937	107	3.13	104	3.43	103	4.36	100
B-3	1670	101	2596	113	3930	107	3.10	103	3.42	103	4.39	101
B-4	1648	100	2480	108	3700	101	3.15	105	3.52	106	4.31	99
B-5	1700	103	2370	104	3643	99	3.14	104	3.50	105	4.38	101
0-1	1727	100	2435	100	3383	100	3.05	100	3.35	100	4.24	100
C-1	1780	103	2273	93	3540	105	3.02	99	3.29	98	4.42	104
C-2	1805	104	2285	94	3348	99	2.98	98	3.20	96	4.16	98
C-3	1758	102	2260	93	3276	97	2.85	94	3.22	96	4.15	98
C-4	1533	89	1985	82	3123	92	2.78	91	3.11	93	4.16	98
C-5	1393	81	1932	79	2913	86	2.75	90	3.10	93	4.26	100
D-1	1495	87	2120	87	3310	98	2.76	90	3.24	97	4.43	104
D-2	1547	90	2057	84	3413	101	2.92	96	3.29	98	4.53	107
D-3	1755	102	2330	96	3546	105	2.97	97	3.40	101	4.53	107
D-4	1760	102	2400	99	3633	107	2.93	96	3.39	101	4.53	107
D-5	1773	103	2490	102	3710	110	2.95	97	3.43	102	4.49	106

Table 4. Admixture Summary Sheet

Admixture	Vertical Reinforcing Steel						Horizontal Reinforcing Steel 4.5 Inch Cover						Horizontal Reinforcing Steel 13.5 Inch Cover					
	Column 1†	Ratio Percent	Column 2††	Ratio Percent	Column 3††	Ratio Percent	Column 1†	Ratio Percent	Column 2††	Ratio Percent	Column 3††	Ratio Percent	Column 1†	Ratio Percent	Column 2†	Ratio Percent	Column 3††	Ratio Percent
0-0	776	100	905	100	0.00195	100	354	100	752	100	0.02405	100	472	100	802	100	0.00205	100
A-1	778	100	1081	119	0.00989	510	234	66	752	100	0.02320	97	348	74	901	112	0.00521	254
A-2	767	99	883	98	0.00258	132	283	80	695	93	0.04470	186	483	102	896	112	0.01179	574
A-3	448	57	843	93	0.00198	102	319	90	845	112	0.02485	103	360	77	860	107	0.00545	266
A-4	366	47	802	89	0.00518	266	295	83	670	89	0.02200	92	390	83	725	90	0.00265	129
A-5	378	49	855	95	0.00655	336	137	39	565	75	0.01940	81	231	49	613	76	0.00950	464
B-1	413	53	873	96	0.00180	94	290	82	799	106	0.02315	96	377	80	896	112	0.00560	273
B-2	472	61	914	101	0.00325	167	425	120	824	109	0.00350	15	425	90	871	109	0.00173	84
B-3	95	12	896	99	0.01275	650	250	71	846	113	0.04890	204	378	80	871	109	0.00300	146
B-4	377	49	883	98	0.00975	500	236	67	826	110	0.02185	91	364	77	870	108	0.00873	426
B-5	342	44	864	95	0.01375	700	201	57	842	112	0.02750	115	365	78	810	101	0.00901	440

† Bond stress for 0.001 inch slip at free end psi

†† Bond stress at ultimate load psi

††† Slip at ultimate load inches

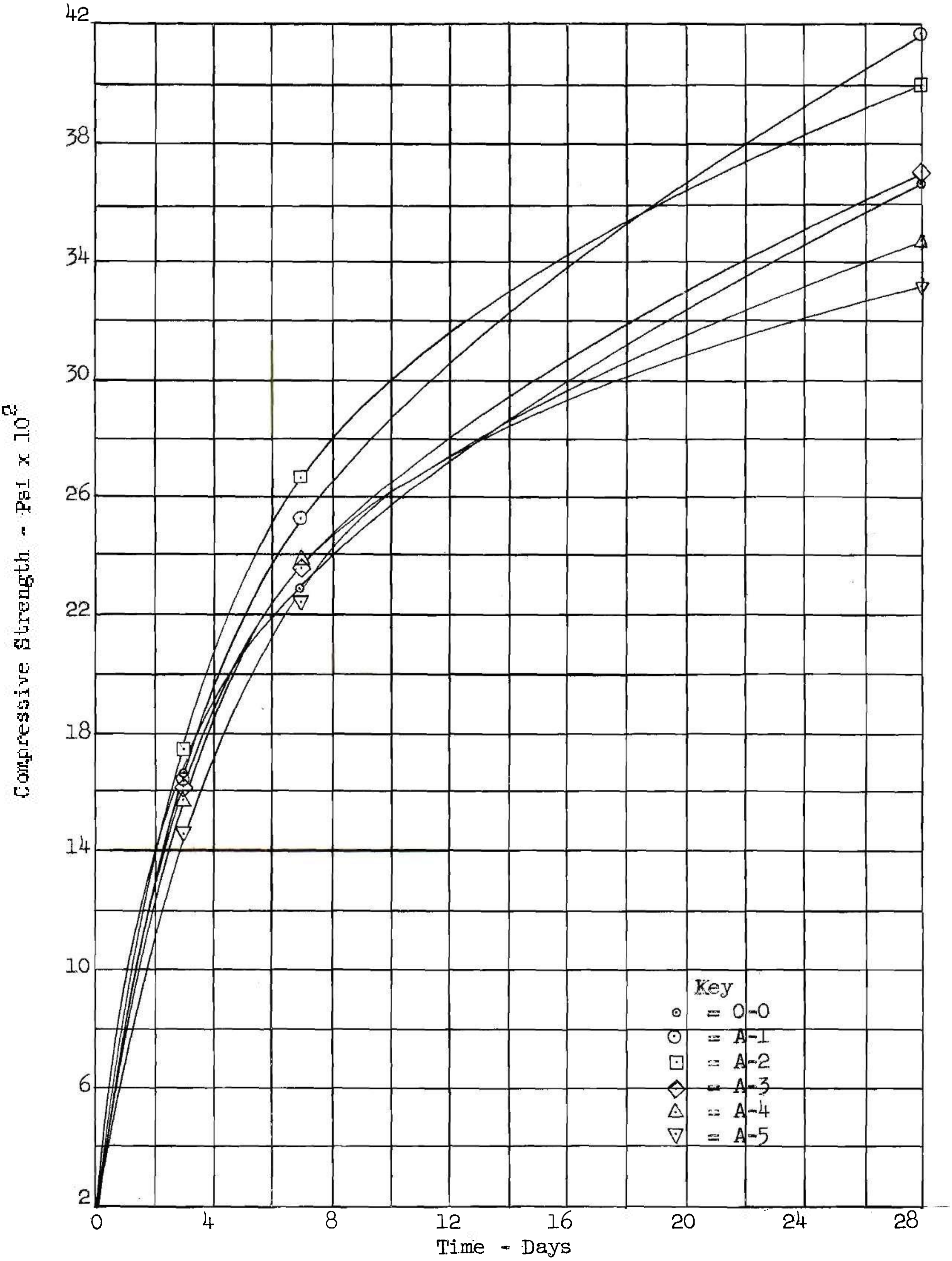


Figure 9. Compressive Strength Vs Age Admixture A

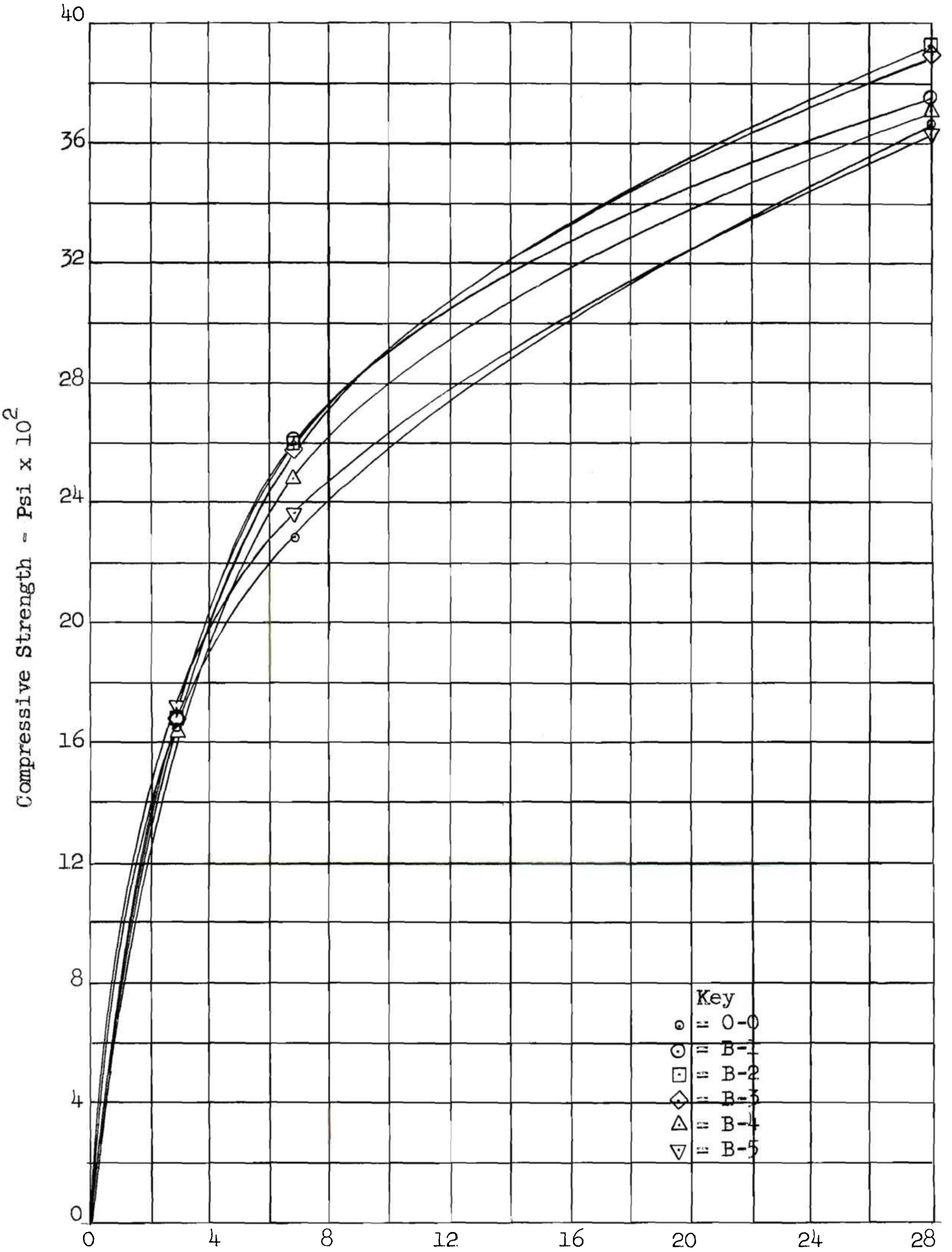
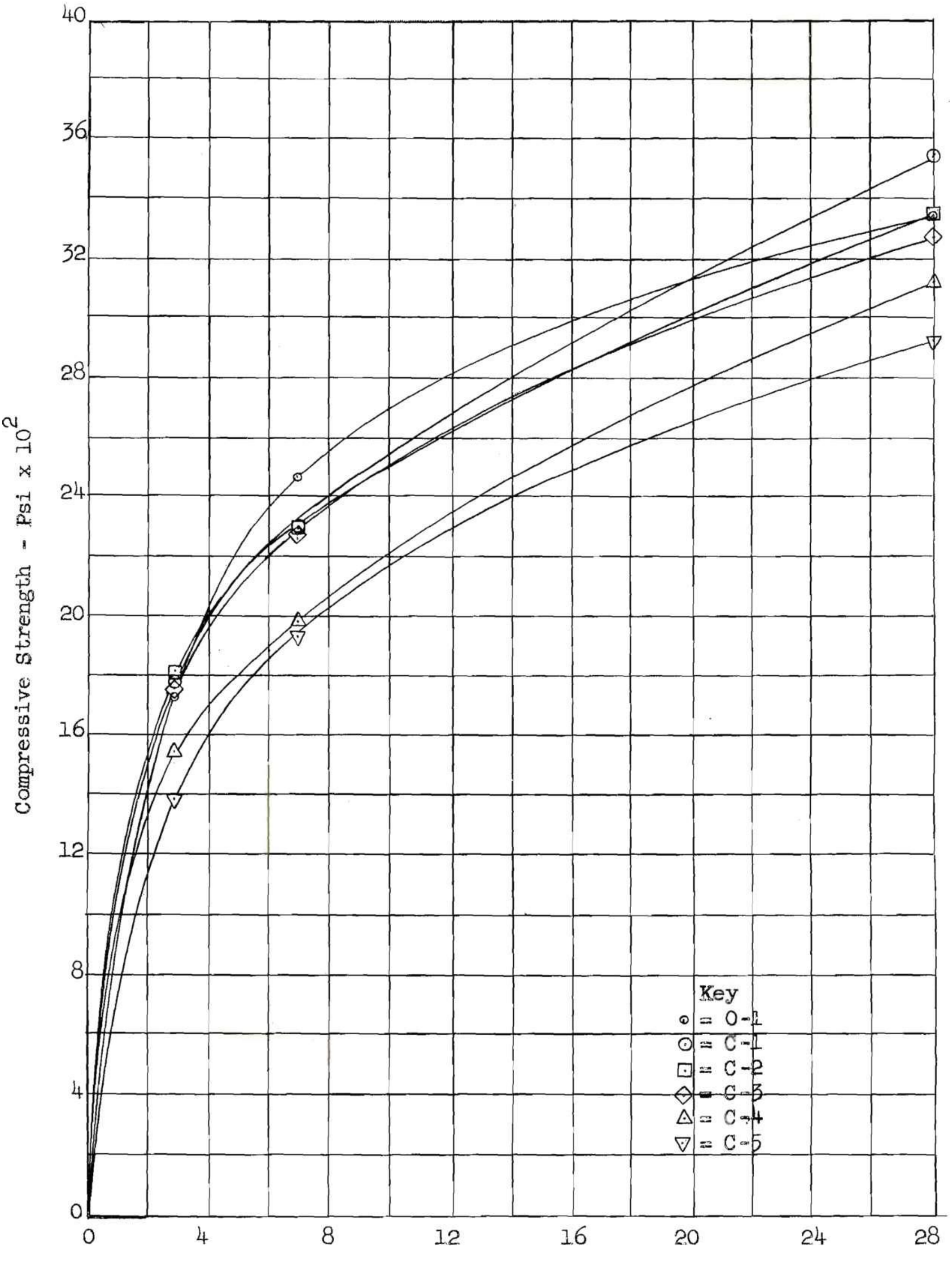


Figure 10. Compressive Strength Vs Age Admixture B



Time - Days

Figure 11. Compressive Strength Vs Age Admixture C

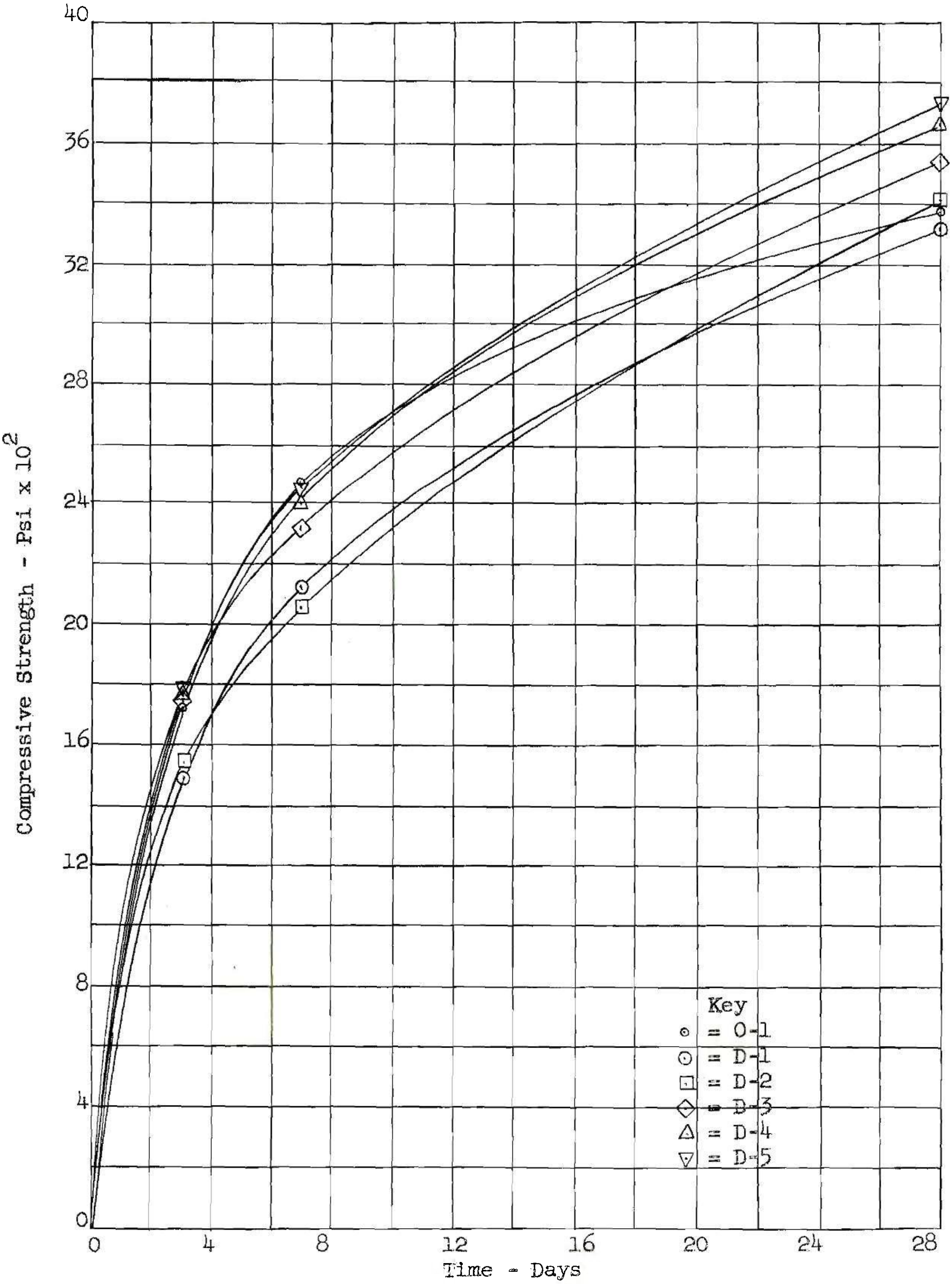


Figure 12. Compressive Strength Vs Age Admixture D

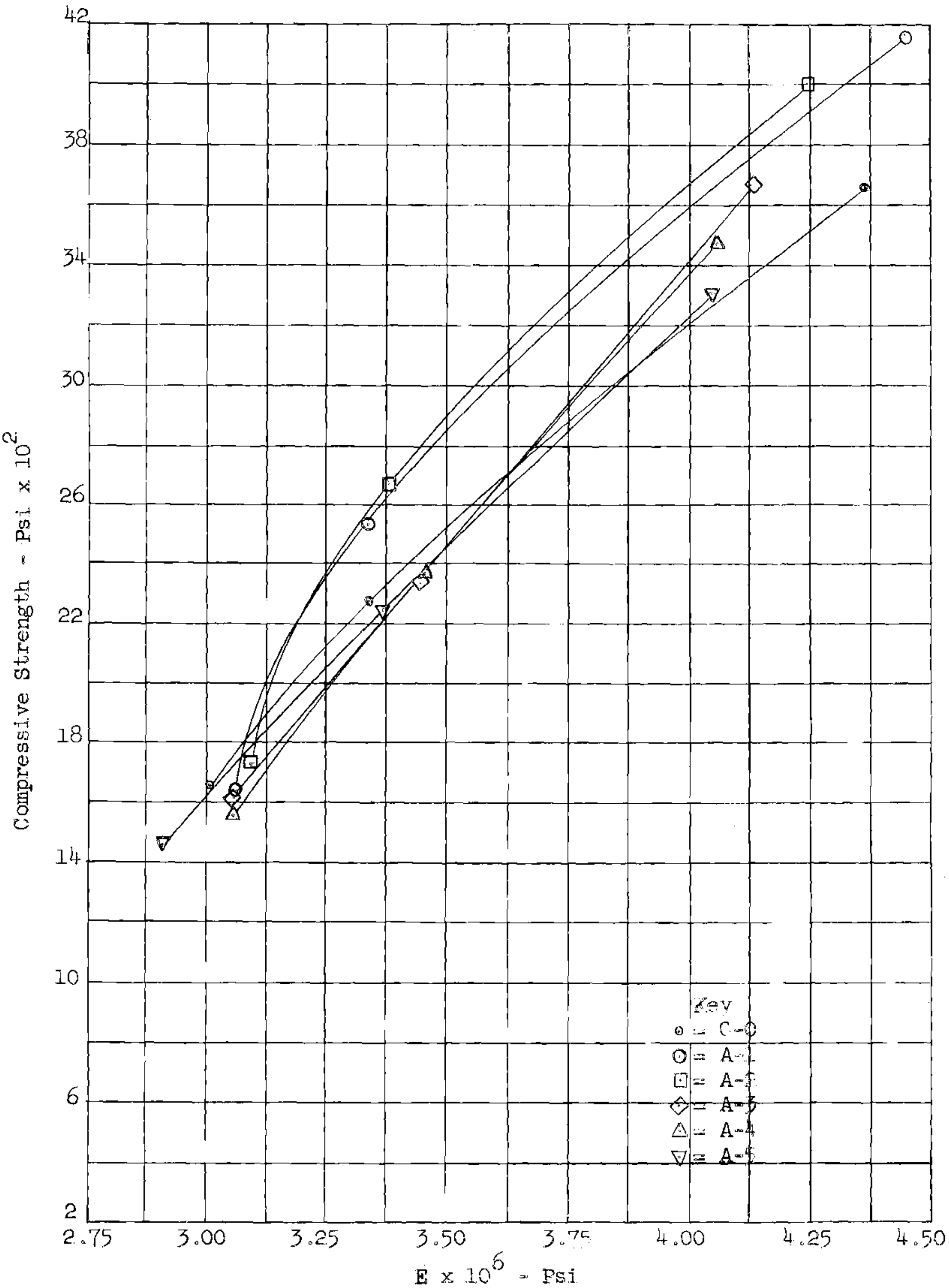


Figure 13.. Young's Modulus Vs Compressive Strength Admixture A

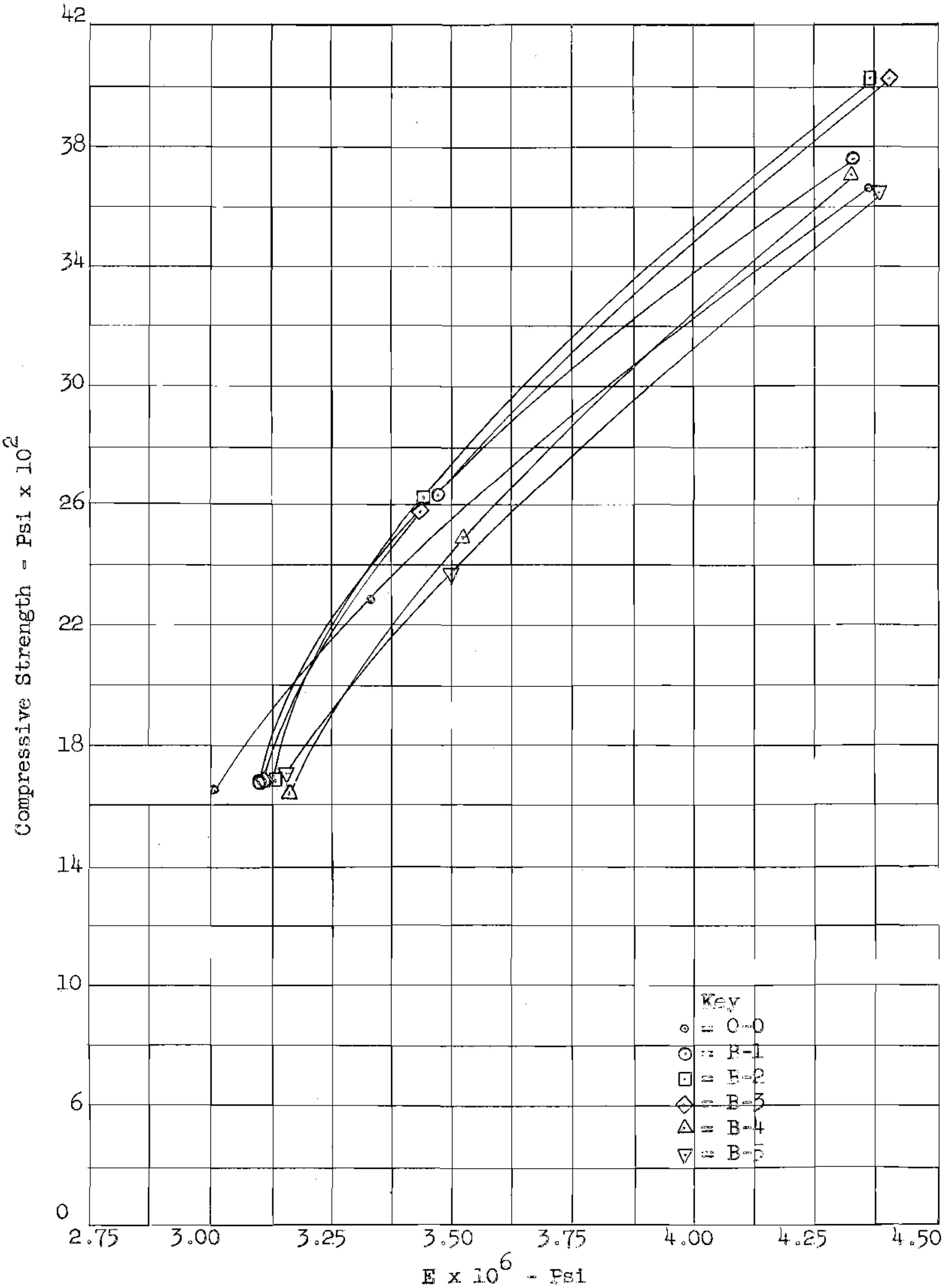


Figure 13. Young's Modulus Vs Compressive Strength Admixture B

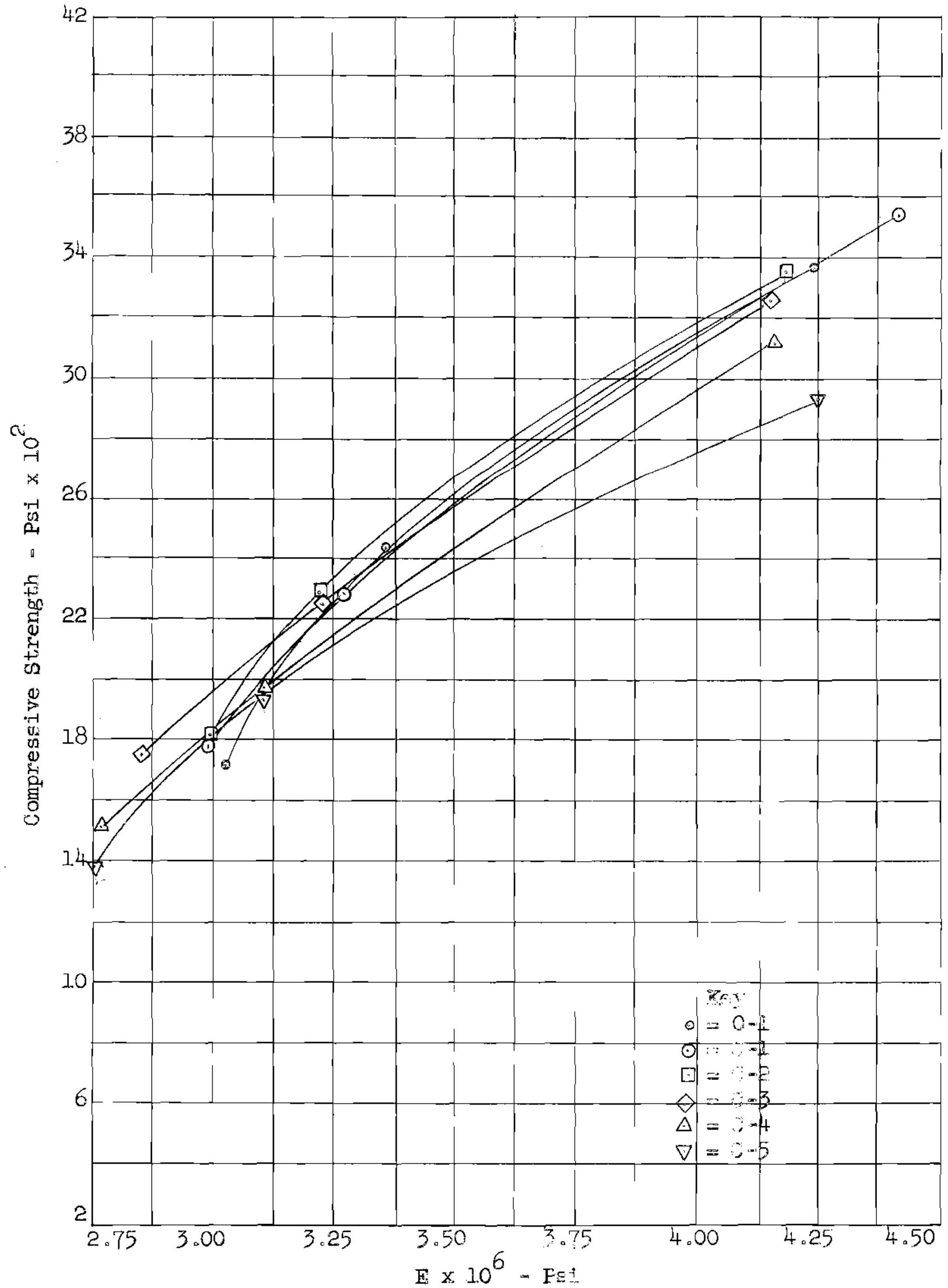


Figure 14. Young's Modulus Vs Compressive Strength Admixture C

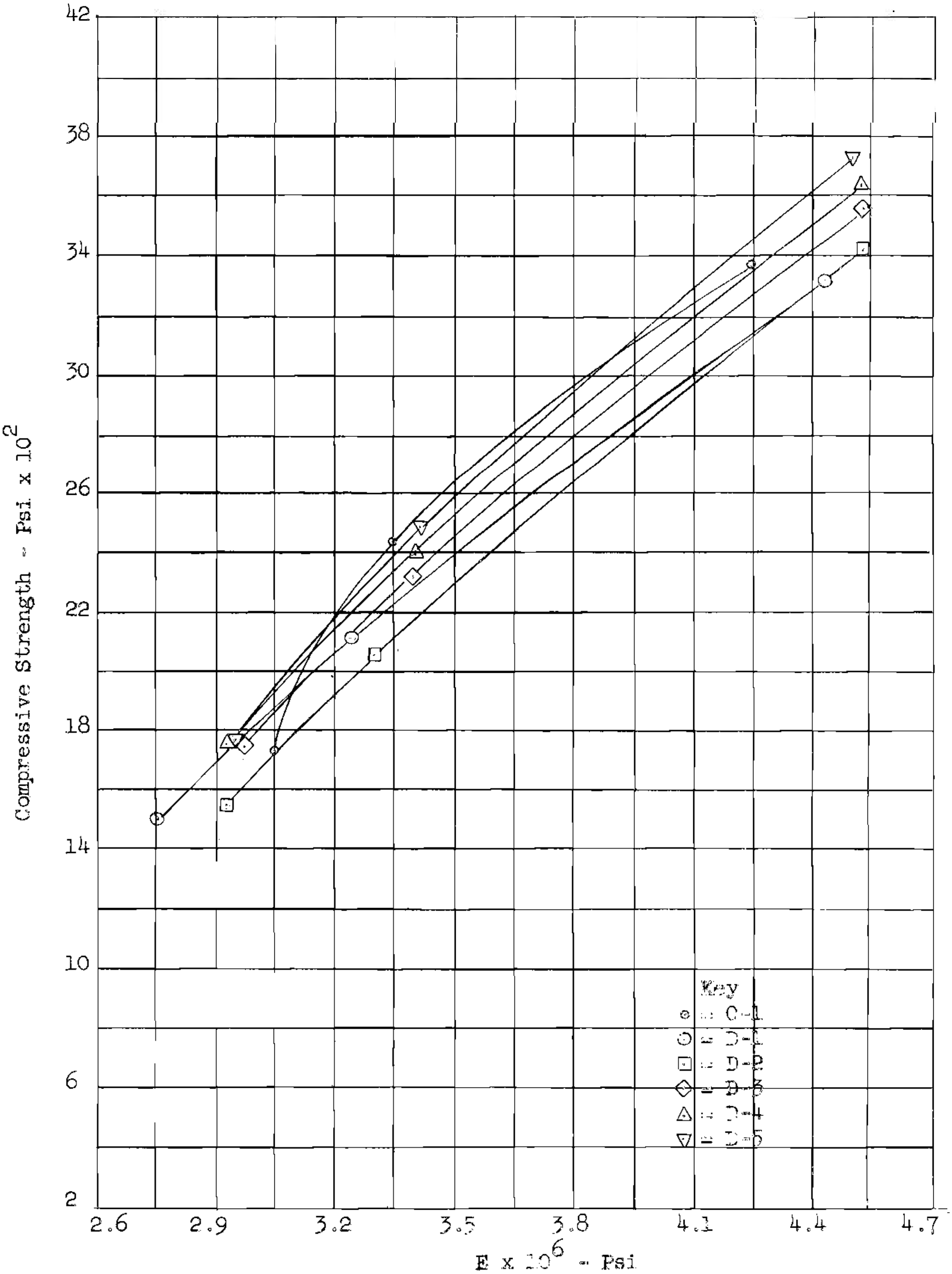


Figure 16. Young's Modulus Vs Compressive Strength Admixture D

CHAPTER V

CONCLUSIONS

From the experimental work carried out in this investigation the following conclusion can be drawn: A thorough and detailed investigation of dispersion agents A and C is economically justified as shown by their abilities to:

a. Entrain air in proportions necessary for highway and other related construction where workability and durability is required.

b. Reduce the cement requirement as much as 3/4 sack per cubic yard while maintaining good workability and relative high compressive strengths for the amount of entrained air present.

c. Reduce bleeding.

d. Produce a more cohesive and workable mixture at reduced water contents.

CHAPTER VI

RECOMMENDATIONS

In any further investigations it is suggested that the following methods and tests be used to provide the information necessary to properly evaluate the admixture.

1. Use a constant cement factor of 4.5 and 6 sacks per cubic yard of concrete.
2. Adjust the fine aggregate to compensate for entrained air.
3. Use a blend of three cements which conform to the requirements for Type I Portland Cement.
4. Use well-graded sound aggregates that are closely controlled in respect to gradation and moisture content.
5. Maintain a constant slump of 3 ± 1/4 inches by adjusting the water-cement ratio.
6. Use admixture concentrations of 0.10 and 0.25 percent by cement weight.
7. Perform the following tests on the plastic and hardened concrete.

Plastic Concrete

a. Consistency.

b. Air Content.

c. Bleeding.

d. Unit Weight.

Hardened Concrete

a. Compressive Strength.

b. Flexural Strength.

c. Resistance to Freezing and Thawing.

d. Volume Change.

e. Bond to Steel.

A P P E N D I X

Table 5. Bleeding Percent Accumulative

Admixture	W_1	W_w	S	C	B	Percent Bleeding
0-0	3923	337	69.3	5.94	254	9.44
A-1	3923	337	68.2	5.85	251	9.42
A-2	3906	330	69.3	5.85	226	8.52
A-3	3888	323	69.0	5.74	218	8.36
A-4	3851	309	68.5	5.49	208	8.34
A-5	3809	293	67.5	5.20	190	8.05
B-1	3917	334	70.6	6.02	243	8.90
B-2	3903	329	69.2	5.83	280	10.59
B-3	3879	320	68.4	5.64	280	10.95
B-4	3875	318	69.3	5.68	282	10.95
B-5	3865	310	68.8	5.52	284	11.32

Bleeding - Volume Per Unit of Surface Area - ML/CM^2

	Time - Minutes							
Admixture	10	20	30	40	70	100	130	160
0-0	0.55	1.77	2.88	3.56	4.50	4.82	4.92	5.01
A-1	0.53	1.44	3.04	3.62	4.66	4.85	4.95	——
A-2	0.73	1.60	2.31	2.96	3.95	4.35	4.46	——
A-3	0.28	1.22	2.02	2.69	3.94	4.25	4.31	——
A-4	0.24	0.83	1.70	2.45	3.78	4.02	4.12	——
A-5	——	0.02	0.44	0.69	1.73	2.86	3.58	3.75
B-1	0.91	2.09	2.82	3.58	4.40	4.73	4.80	——
B-2	0.59	0.99	2.37	3.00	4.35	5.41	5.54	——
B-3	0.55	2.43	3.78	4.63	4.98	5.54	——	——
B-4	0.51	1.93	2.96	3.80	5.10	5.40	5.50	5.54
B-5	0.24	1.95	3.16	4.27	5.17	5.56	5.61	——

W_1 = Total weight of component ingredients in the batch in lbs.

W_w = Total weight of mixing water added to batch in lbs.

S = Weight of sample in pounds.

C = Weight of water in the test specimen in pounds.

B = Total quantity of bleeding water withdrawn from the test specimen in milliliters.

Table 6. Bleeding Percent Accumulative

Admixture	W_1	W_w	S	C	B	Percent Bleeding
O-1	3923	337	69.5	5.97	193	7.13
C-1	3921	336	69.4	5.94	192	7.12
C-2	3907	331	68.5	5.72	144	5.50
C-3	3890	324	67.5	5.63	142	5.56
C-4	3859	312	65.8	5.33	140	5.80
C-5	3827	300	64.8	5.08	139	6.03
D-1	3922	336	67.4	5.78	218	8.32
D-2	3918	335	67.4	5.77	222	8.50
D-3	3911	332	66.4	5.64	249	9.71
D-4	3910	332	66.4	5.64	286	11.19
D-5	3902	329	66.2	5.57	287	11.35

Bleeding - Volume Per Unit of Surface Area - ML/CM^2

	Time - Minutes									
Admixture	10	20	30	40	70	100	130	160	190	220
O-1	0.20	1.05	1.64	2.33	3.58	3.76	3.81	——	——	——
C-1	0.38	0.83	1.52	2.41	3.66	3.74	3.80	——	——	——
C-2	0.20	0.51	0.85	1.30	2.41	2.76	2.84	——	——	——
C-3	0.16	0.40	0.79	0.99	2.06	2.47	2.70	2.76	2.80	——
C-4	0.12	0.32	0.55	0.77	1.58	2.37	2.68	2.74	2.76	——
C-5	0.16	0.32	0.51	0.79	1.54	2.29	2.52	2.68	2.72	2.74
D-1	0.63	1.81	2.60	3.24	4.10	4.30	4.31	——	——	——
D-2	0.59	1.77	2.61	3.40	4.10	4.30	4.38	——	——	——
D-3	0.95	2.39	3.34	4.15	4.78	4.90	4.92	——	——	——
D-4	0.59	1.59	2.63	3.36	4.86	5.45	5.61	5.65	——	——
D-5	0.34	1.26	2.09	2.74	4.10	4.82	5.38	5.68	——	——

W_1 = Total weight of component ingredients in the batch in lbs.

W_w = Total weight of mixing water added to batch in lbs.

S = Weight of sample in lbs.

C = Weight of water in the test specimen in lbs.

B = Total quantity of bleeding water withdrawn from the test specimen in milliliters.

Table 7. Bleeding Test Data

Admixture Bleeding - Volume in Mil.																						Time
0-0	A-1	A-2	A-3	A-4	A-5	B-1	B-2	B-3	B-4	B-5	0-1	C-1	C-2	C-3	C-4	C-5	D-1	D-2	D-3	D-4	D-5	Min.
28	27	37	14	12	0	46	30	28	26	12	10	19	10	8	6	8	32	30	48	30	17	10
90	73	81	62	42	1	106	50	123	98	99	53	42	26	20	16	17	92	90	121	81	64	20
146	154	117	102	86	22	143	120	191	150	160	83	77	43	40	28	26	132	132	169	133	106	30
180	183	150	136	124	35	178	152	234	192	216	118	122	66	50	39	40	164	180	210	170	139	40
228	236	200	199	191	88	223	220	252	258	262	181	185	122	104	80	78	208	208	242	246	208	70
244	245	220	215	203	145	239	274	280	273	282	190	189	140	125	120	116	217	218	248	276	244	100
249	250	226	218	208	160	243	280	—	278	284	193	192	144	137	136	133	218	222	249	284	272	130
254	—	—	—	—	180	—	—	—	282	—	—	—	—	140	139	136	—	—	—	286	287	160
—	—	—	—	—	190	—	—	—	—	—	—	—	—	142	140	138	—	—	—	—	—	190
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	139	—	—	—	—	—	220
80	80	78	78	78	76	77	77	76	77	76	74	74	74	74	74	74	74	74	74	74	74	T°-F
69.3	68.2	69.3	69.0	68.5	67.5	70.6	69.2	68.4	69.3	68.8	69.5	69.4	68.5	67.5	65.8	64.8	67.4	67.4	66.4	66.4	66.2	Wt of Sample Lbs.

Table 8. Plastic Concrete Analysis

Admixture Number	Mix Design Cement Lbs.	Mix Design Water Lbs.	Mix Design Admixture Grams	Lab Temperature °F	Slump In.	Percent Air	Wt. 1/2 Cu. Ft. Plastic Concrete Lbs.	Container Factor	Unit Weight Pcf
0-0	517	337	0.0	80	2-7/8	2.15	72.52	2.02	146.50
A-1	517	337	58.5	80	2-15/16	2.20	72.47	2.02	146.40
A-2	506	330	115.0	78	2-7/8	2.30	72.47	2.02	146.40
A-3	495	323	224.5	78	3-1/8	3.00	72.27	2.02	146.00
A-4	472	309	321.0	78	3	3.50	71.72	2.03	145.60
A-5	446	293	506.0	76	2-7/8	6.00	70.40	2.02	142.20
B-1	513	334	58.0	77	2-3/4	2.50	72.51	2.02	146.48
B-2	504	329	115.0	77	2-15/16	2.65	72.11	2.03	146.40
B-3	489	320	222.0	76	3	2.70	72.47	2.02	146.40
B-4	487	318	329.0	79	2-3/4	2.80	72.01	2.03	146.20
B-5	485	310	538.0	78	3	3.10	71.98	2.02	145.40
0-1	517	337	0.0	82	2-7/8	2.15	72.40	2.02	146.25
C-1	515	336	58.4	81	2-15/16	2.65	72.37	2.02	146.20
C-2	506	331	115.0	81	2-7/8	3.15	71.80	2.03	145.75
C-3	496	324	224.5	81	2-13/16	4.40	71.14	2.02	143.70
C-4	477	312	324.0	84	2-7/8	5.60	69.85	2.03	140.79
C-5	457	300	517.5	84	2-15/16	7.80	68.25	2.02	139.86
D-1	516	336	58.0	84	2-3/4	2.25	71.92	2.03	145.99
D-2	513	335	116.0	83	2-7/8	2.45	71.77	2.03	145.70
D-3	509	332	230.0	84	3	2.70	71.78	2.02	145.00
D-4	508	332	345.0	85	3	2.95	71.28	2.03	144.70
D-5	503	329	571.0	85	3-1/8	3.40	71.10	2.02	143.62

Table 9. Identification Tests

Admixture	Unit Wt. Pcf	Wt. Per Cy Lbs.	S_3 Ft^3	N Bags/Cy	Yield Ft^3/Bag	Cement Factor	V_3 Ft^3	T Pcf	T-W Pcf	Percent Air Calculated	Percent Air Pressure	Difference
0-0	146.50	3923	26.80	5.50	4.88	5.53	26.60	147.52	1.02	0.69	2.15	1.46
A-1	146.40	3923	26.80	5.50	4.88	5.53	26.60	147.52	1.12	0.77	2.20	1.43
A-2	146.40	3906	26.70	5.38	5.00	5.40	26.41	147.89	1.49	1.01	2.30	1.29
A-3	146.00	3888	26.61	5.26	5.07	5.34	26.28	147.94	1.94	1.31	3.00	1.69
A-4	145.60	3851	26.52	5.02	5.28	5.12	25.93	148.51	2.91	1.97	3.50	1.53
A-5	142.20	3809	26.78	4.75	5.64	4.79	25.52	149.25	7.05	4.80	6.00	1.20
B-1	146.48	3917	26.75	5.46	4.89	5.52	26.52	147.69	1.21	0.82	2.50	1.68
B-2	146.40	3903	26.68	5.36	4.97	5.44	26.41	147.79	1.39	0.94	2.65	1.71
B-3	146.40	3879	26.51	5.20	5.10	5.30	26.20	148.05	1.65	1.12	2.70	1.58
B-4	146.20	3875	26.50	5.18	5.12	5.27	26.15	148.14	1.94	1.31	2.80	1.49
B-5	145.40	3865	26.58	5.16	5.15	5.24	26.02	148.54	3.14	2.10	3.10	1.00
0-1	146.25	3923	26.82	5.50	4.88	5.53	26.60	147.52	1.27	0.86	2.15	1.29
C-1	146.20	3921	26.81	5.48	4.90	5.52	26.58	147.52	1.32	0.89	2.65	1.76
C-2	145.75	3907	26.81	5.38	4.98	5.42	26.45	147.71	1.96	1.33	3.15	1.82
C-3	143.70	3890	27.08	5.27	5.15	5.24	26.29	147.93	4.23	2.86	4.40	1.54
C-4	140.79	3859	27.38	5.07	5.40	5.00	26.00	148.42	7.63	5.15	5.60	0.45
C-5	139.86	3827	27.40	4.86	5.64	4.79	25.71	148.85	8.99	6.05	7.80	1.75
D-1	145.99	3922	26.94	5.49	4.91	5.50	26.59	147.49	1.50	1.02	2.25	1.23
D-2	145.70	3918	26.94	5.46	4.93	5.48	26.56	147.51	1.81	1.23	2.45	1.22
D-3	145.00	3911	26.98	5.42	4.97	5.44	26.48	147.70	2.70	1.83	2.70	0.87
D-4	144.70	3910	27.00	5.40	5.00	5.40	26.47	147.72	3.02	2.04	2.95	0.91
D-5	143.62	3902	27.23	5.35	5.10	5.30	26.41	147.77	4.15	2.81	3.40	0.59

S = Volume of concrete produced per batch in cubic feet
N = Number of bags of cement in the batch
V = Total absolute volume of the component ingredients in the batch in cubic feet
T = Theoretical weight of the concrete in pounds per cubic feet computed on an air free basis
W = Weight of concrete in pounds per cubic feet

Table 10. Compressive Strength Tests

Age Days	Test Cyl. No.	Admixture Compressive Strength - Psi										
		0-0	A-1	A-2	A-3	A-4	A-5	B-1	B-2	B-3	B-4	B-5
	1	1680	1610	1750	1680	1570	1430	1610	1540	1890	1620	1640
3	2	1605	1605	1840	1590	1570	1420	1765	1820	1330	1635	1780
	3	1655	1640	1625	1570	1570	1465	1610	1650	1890	1690	1680
	Average	1647	1632	1740	1610	1570	1438	1660	1670	1670	1648	1700
	1	2200	2690	2650	2260	2450	2150	2720	2550	2550	2485	2460
7	2	2370	2620	2650	2410	2380	2270	2640	2560	2700	2370	2300
	3	2280	2210	2720	2350	2280	2300	2520	2730	2540	2585	2350
	Average	2290	2530	2673	2340	2370	2240	2627	2613	2596	2480	2370
	1	3820	4175	3980	3680	3520	3275	3590	4050	4100	3590	3500
28	2	3310	4300	4020	3700	3400	3400	3860	4065	4150	3780	3700
	3	3860	4075	4000	3700	3520	3275	3820	3695	3540	3730	3730
	Average	3663	4183	4000	3693	3480	3317	3757	3937	3930	3700	3643

Table 11. Compressive Strength Tests

Age Days	Test Cyl. No.	Admixture Compressive Strength - Psi										
		O-1	C-1	C-2	C-3	C-4	C-5	D-1	D-2	D-3	D-4	D-5
	1	1760	1690	1825	1775	1460	1435	1570	1565	1870	1760	1980
3	2	1655	1990	1790	1620	1585	1400	1460	1535	1850	1780	1360
	3	1765	1660	1800	1880	1615	1345	1455	1540	1545	1740	1980
	Average	1727	1780	1805	1758	1533	1393	1495	1547	1755	1760	1773
	1	2570	2380	2235	2225	1990	1945	2180	1950	2320	2420	2340
7	2	2395	2200	2300	2315	1965	1910	2060	2060	2355	2430	2550
	3	2340	2240	2220	2240	2000	1940	2120	2160	2315	2350	2580
	Average	2435	2273	2285	2260	1985	1932	2120	2057	2330	2400	2490
	1	3370	3720	3400	3260	3100	3050	3400	3700	3420	3620	3660
28	2	3370	3500	3345	3310	3140	2860	3360	3020	3590	3550	3850
	3	3410	3400	3300	3260	3130	2830	3120	3520	3640	3730	3630
	Average	3383	3540	3348	3276	3123	2913	3310	3413	3546	3633	3710

Table 12. Dynamic Modulus of Elasticity

Age Days	Test Cycle No.	0-0 Wt. Lbs	0-0 †N x 10^2	A-1 Wt. Lbs	A-1 N x 10^2	A-2 Wt. Lbs	A-2 N x 10^2	A-3 Wt. Lbs	A-3 N x 10^2	A-4 Wt. Lbs	A-4 N x 10^2	A-5 Wt. Lbs	A-5 N x 10^2	Ex10^6 Psi
	1	28.9	29.8	28.9	29.6	29.1	29.7	28.7	30.9	28.9	30.2	28.4	29.7	
3	2	29.1	29.8	29.2	30.6	29.1	30.5	28.9	30.0	29.0	30.0	28.3	29.6	
	3	29.0	29.8	28.9	30.0	28.9	30.6	29.0	30.0	28.7	30.8	28.3	29.7	
	Average	29.0	29.8	29.0	30.1	29.0	30.3	28.9	30.3	28.9	30.3	28.3	29.7	
		3.01		3.06		3.10		3.09		3.09		2.92		Avg.
	1	29.1	31.5	29.1	31.3	29.1	31.5	29.1	32.5	28.8	32.1	28.1	32.0	
7	2	29.0	31.2	29.0	31.4	29.1	31.5	28.9	31.9	29.1	31.9	28.4	32.0	
	3	29.1	31.2	29.1	31.4	29.0	31.7	28.8	32.0	28.9	32.0	28.2	32.1	
	Average	29.1	31.3	29.1	31.4	29.1	31.6	28.9	31.9	28.9	32.0	28.2	32.0	
		3.32		3.34		3.38		3.43		3.44		3.37		Avg.
	1	28.9	36.4	29.1	36.4	28.9	35.4	29.1	35.1	29.1	34.0	28.3	35.0	
28	2	29.0	36.4	29.0	35.3	29.0	35.8	28.7	35.0	29.0	35.1	28.3	35.0	
	3	29.0	36.5	29.0	36.9	29.1	35.0	28.7	35.1	28.8	34.9	28.4	35.0	
	Average	29.0	36.4	29.0	36.2	29.0	35.4	28.8	35.1	29.0	34.7	28.3	35.0	
		4.35		4.43		4.24		4.13		4.06		4.04		

† N = resonance frequency in cycles/sec.

Table 13. Dynamic Modulus of Elasticity

Age Days	Test Cycle No.	Admixtures 0-0 Wt. Lbs	0-0 †N x 10^2	B-1 Wt. Lbs	B-1 N x 10^2	B-2 Wt. Lbs	B-2 N x 10^2	B-3 Wt. Lbs	B-3 N x 10^2	B-4 Wt. Lbs	B-4 N x 10^2	B-5 Wt. Lbs	B-5 N x 10^2	Ex10^6 Psi
	1	28.9	29.8	28.8	30.0	28.8	30.7	29.1	30.4	29.2	30.5	29.0	30.2	
3	2	29.1	29.8	29.5	30.3	28.9	30.6	29.1	29.8	29.0	30.6	28.9	30.8	
	3	29.0	29.8	29.2	30.0	29.0	30.2	29.1	30.4	29.1	30.5	28.8	30.6	
	Average	29.0	29.8	29.2	30.1	28.9	30.5	29.1	30.2	29.1	30.5	28.9	30.5	
		3.01		3.08		3.13		3.10		3.15		3.14		Avg.
	1	29.1	31.5	29.3	32.0	28.9	32.3	29.1	31.5	29.1	32.2	28.8	32.5	
7	2	29.0	31.2	29.1	32.2	29.0	31.6	29.1	32.2	29.1	32.2	29.0	32.2	
	3	29.1	31.2	29.2	31.5	29.0	31.4	29.3	31.6	29.0	32.2	28.8	32.0	
	Average	29.1	31.3	29.2	31.9	29.0	31.8	29.2	31.8	29.1	32.2	28.9	32.2	
		3.32		3.46		3.43		3.42		3.52		3.50		Avg.
	1	28.9	36.4	29.0	35.8	28.8	36.5	29.1	36.5	29.1	35.2	29.2	36.0	
28	2	29.0	36.4	29.2	35.5	29.3	36.1	29.1	36.5	29.0	36.0	28.9	36.1	
	3	29.0	36.5	29.0	35.8	29.2	35.1	29.1	35.0	29.1	35.8	28.8	35.9	
	Average	29.0	36.4	29.1	35.7	29.1	35.9	29.1	36.0	29.1	35.7	29.0	36.0	
		4.35		4.31		4.36		4.39		4.31		4.38		Avg.

† N = resonance frequency in cycles/sec.

Table 14. Dynamic Modulus of Elasticity

Age Days	Test Cycle No.	Admixtures O-1 Wt. Lbs	O-1 †N x 10^2	C-1 Wt. Lbs	C-1 N x 10^2	C-2 Wt. Lbs	C-2 N x 10^2	C-3 Wt. Lbs	C-3 N x 10^2	C-4 Wt. Lbs	C-4 N x 10^2	C-5 Wt. Lbs	C-5 N x 10^2	$E \times 10^6$ Psi
	1	29.2	30.5	29.0	29.8	29.0	30.2	28.3	29.4	27.8	29.5	27.7	29.2	
3	2	29.0	29.2	29.0	29.8	29.3	29.9	28.4	29.2	27.6	29.8	27.7	29.3	
	3	29.1	30.4	29.0	29.8	28.8	29.1	28.2	29.5	27.8	29.0	27.6	29.1	
	Average	29.1	30.0	29.0	29.8	29.0	29.7	28.3	29.4	27.7	29.4	27.7	29.2	
		3.05		3.02		2.98		2.85		2.78		2.75		Avg.
	1	29.1	31.6	29.1	31.2	28.7	29.6	28.0	31.3	28.0	30.8	27.5	30.9	
7	2	29.2	31.3	29.0	31.3	28.8	30.5	28.2	31.5	28.0	30.4	27.9	31.2	
	3	29.0	31.2	29.0	31.2	29.2	30.8	28.1	31.0	27.8	31.5	27.6	31.0	
	Average	29.1	31.4	29.0	31.2	28.9	30.3	28.1	31.3	27.9	30.9	27.7	31.0	
		3.35		3.29		3.20		3.22		3.11		3.10		Avg.
	1	29.1	35.4	29.0	36.2	28.9	35.5	28.5	35.3	28.0	35.5	28.0	36.5	
28	2	29.2	35.1	29.0	36.1	28.9	35.1	28.3	35.5	28.0	36.1	27.9	36.0	
	3	29.2	35.3	29.0	36.2	28.9	35.1	28.3	35.3	27.8	35.8	27.9	36.0	
	Average	29.2	35.3	29.0	36.2	28.9	35.2	28.4	35.4	27.9	35.8	27.9	36.2	
		4.24		4.42		4.16		4.15		4.16		4.26		Avg.

† N = resonance frequency in cycles/sec.

Table 15. Dynamic Modulus of Elasticity

Age Days	Test Cycle No.	Admixtures O-1 Wt. Lbs	O-1 †N x 10^2	D-1 Wt. Lbs	D-1 N x 10^2	D-2 Wt. Lbs	D-2 N x 10^2	D-3 Wt. Lbs	D-3 N x 10^2	D-4 Wt. Lbs	D-4 N x 10^2	D-5 Wt. Lbs	D-5 N x 10^2	E x 10^6 Psi
	1	29.2	30.5	28.6	28.8	28.7	30.0	28.2	30.0	28.9	29.4	28.3	30.5	
3	2	29.0	29.2	28.8	28.6	28.6	29.5	28.4	30.0	28.8	29.5	28.2	29.6	
	3	29.1	30.4	28.8	28.6	28.5	29.4	28.8	29.6	28.8	29.5	28.4	29.5	
	Average	29.1	30.0	28.7	28.7	28.6	29.6	28.5	29.9	28.8	29.5	28.3	29.9	
		3.05		2.76		2.92		2.97		2.93		2.95		Avg.
	1	29.1	31.6	28.6	30.8	28.7	31.5	28.7	31.9	28.5	31.9	28.5	31.8	
7	2	29.2	31.3	29.1	31.5	28.7	31.3	28.7	32.1	28.6	32.0	28.5	32.3	
	3	29.0	31.2	28.6	30.9	28.6	31.4	28.8	31.8	28.7	31.7	28.7	32.1	
	Average	29.1	31.4	28.8	31.1	28.7	31.4	28.7	31.9	28.6	31.9	28.6	32.1	
		3.35		3.24		3.29		3.40		3.39		3.43		Avg.
	1	29.1	35.4	28.6	35.8	28.5	37.0	28.7	36.4	28.8	36.4	28.4	37.0	
28	2	29.2	35.1	28.8	36.2	28.7	37.0	28.9	36.9	28.7	36.8	28.5	36.7	
	3	29.2	35.3	28.7	35.3	28.9	36.5	28.8	37.0	28.7	36.8	28.5	36.6	
	Average	29.2	35.3	28.7	35.8	28.7	36.8	28.8	36.8	28.7	36.7	28.5	36.8	
		4.24		4.43		4.53		4.53		4.53		4.49		Avg.

† N = resonance frequency in cycles/sec.

Table 16. Bond Stress For Vertical Reinforcing Steel

	Concrete Speciman No.	Admixtures 0-0	A-1	A-2	A-3	A-4	A-5	B-1	B-2	B-3	B-4	B-5
Bond Stress For 0.001 Inch Strip At Free End Psi	1	752	850	850	519	354	378	354	472	71	354	377
	2	800	707	684	378	378	378	472	472	118	400	307
	Average	776	778	767	448	366	378	413	472	95	377	342
† Bond Stress At Ultimate Load Psi	1	878	932	916	925	660	850	896	896	850	896	846
	2	932	1230	850	861	944	861	850	933	943	870	882
	Average	905	1081	883	843	802	855	873	914	896	883	864
†† Slip At Ultimate Load Inches	1	0.00245	0.00038	0.00016	0.00259	0.00036	0.00340	0.00200	0.00550	0.01050	0.00463	0.00650
	2	0.00145	0.01940	0.00500	0.00138	0.01000	0.00970	0.00160	0.00100	0.01500	0.00512	0.00725
	Average	0.00195	0.00989	0.00258	0.00198	0.00518	0.00655	0.00180	0.00325	0.01275	0.00975	0.01375
Type of Failure	1	Bond	Block Cracked	Block Cracked	Bond	Bond	Bond	Bond	Bond	Bond	Bond	Bond
	2	Bond	Block Cracked	Bond	Bond	Bond	Bond	Bond	Bond	Bond	Bond	Bond
Remarks	1	—	—	—	—	—	—	Rod Not Perfectly Plumb	—	—	—	—
	2	—	Leakage At Water Stop	—	Rod Not Perfectly Plumb	—	—	Leakage At Water Stop	—	Leakage At Water Stop	—	—

† Ultimate load recorded when continued loading produced no further increase in bond stress

†† Measured from free end

Table 17. Bond Stress For Reinforcing Steel - 4.5 Inch Concrete Cover

	Concrete Speciman No.	Admixtures 0-0	A-1	A-2	A-3	A-4	A-5	B-1	B-2	B-3	B-4	B-5
Bond Stress For 0.001 Inch Slip At Free End Psi	1	330	165	330	260	260	71	378	425	358	260	212
	2	378	303	236	378	330	202	202	425	142	212	189
	Average	354	234	283	319	295	137	290	425	250	236	201
† Bond Stress At Ultimate Load Psi	1	658	846	752	845	540	330	846	752	846	800	860
	2	846	658	638	845	800	800	752	896	846	846	823
	Average	752	752	695	845	670	565	799	824	846	826	842
†† Slip At Ultimate Load Inches	1	0.02800	0.03480	0.04700	0.03750	0.00200	0.03100	0.02450	0.00500	0.04580	0.02060	0.04000
	2	0.02010	0.01159	0.04240	0.01220	0.04200	0.00780	0.02180	0.00200	0.05200	0.02310	0.03500
	Average	0.02405	0.02320	0.04470	0.02485	0.02200	0.01940	0.02315	0.00350	0.04890	0.02185	0.02750
Type of Failure	1	Bond	Bond	Bond	Bond	Bond	Bond	Bond	Bond	Bond	Bond	Bond
	2	Bond	Bond	Bond	Bond	Bond	Bond	Bond	Bond	Bond	Bond	Bond
Remarks	1	—	Leakage At Water Stop	—	—	—	Leakage At Water Stop	Rod Not Perfectly Plumb	—	—	—	—
	2	—	Leakage At Water Stop	—	—	—	Rod Not Perfectly Plumb	Leakage At Water Stop	—	Leakage At Water Stop	—	—

† Ultimate load recorded when continued loading produced no further increase in bond stress

†† Measured from free end

Table 18. Bond Stress For Horizontal Reinforcing Steel - 13.5 Inch Concrete Cover

	Concrete Speciman No.	Admixtures 0-0	A-1	A-2	A-3	A-4	A-5	B-1	B-2	B-3	B-4	B-5
Bond Stress For 0.001 Inch Slip At Free End Psi	1	519	378	658	342	472	260	281	425	425	421	400
	2	425	307	307	378	307	201	472	425	330	307	330
	Average	472	348	483	360	390	231	377	425	378	364	365
† Bond Stress At Ultimate Load Psi	1	708	896	896	858	650	896	896	896	896	940	750
	2	896	906	896	861	800	330	896	846	846	800	870
	Average	802	901	896	860	725	613	896	871	871	870	810
†† Slip At Ultimate Load Inches	1	0.00140	0.00487	0.00470	0.00580	0.00100	0.01500	0.00570	0.00205	0.00280	0.00821	0.00976
	2	0.00270	0.00554	0.01887	0.00510	0.00430	0.00400	0.00550	0.00140	0.00320	0.00925	0.00826
	Average	0.00205	0.00521	0.01179	0.00545	0.00265	0.00950	0.00560	0.00173	0.00300	0.00873	0.00901
Type of Failure	1	Bond	Bond	Bond	Bond	Bond	Bond	Bond	Bond	Bond	Bond	Bond
	2	Bond	Bond	Bond	Bond	Bond	Bond	Bond	Bond	Bond	Bond	Bond
Remarks	1	----	Leakage At Water Stop	----	----	----	----	Leakage At Water Stop	----	----	----	----
	2	----	Leakage At Water Stop	----	----	----	----	----	----	----	----	----

† Ultimate load recorded when continued loading produced no further increase in bond stress

†† Measured from free end

Table 19. Summary of Physical Properties of Fine and Coarse Aggregate

Properties	FA	CA
Abrasion - percent (Los Angeles)	——	57.4
Absorption - percent	1.42	0.32
Fineness Modulus	2.39	7.00
Organic Impurities	None	None
Material Passing No. 200 Sieve - percent	1.40	0.40
Soundness of Aggregate - percent	7.23	——
Specific Gravity		
Bulk (Dry)	2.53	2.62
Bulk (SSD)	2.57	2.63
Apparent	2.62	2.65
Unit Weight - pcf	95.4	97.6
Unit Weight of Mixed Aggregate is 124 pcf and consists of - percent	40.0	60.0
Altered Physical Properties of Fine and Coarse Aggregates for use in Testing Admixtures for Concrete (C237-55)		
Fineness Modulus	2.70	7.00
Unit Weight of Mixed Aggregate is 120.8 pcf and consists of - percent	44.5	55.5

FINE AGGREGATE ACCEPTANCE TESTS

A. Specific Gravity and Absorption of Fine Aggregate

ASTM Designation C128-42

Bulk Specific Gravity (dry) $= \frac{A}{V-W} = 2.53$

Bulk Specific Gravity (SSD) $= \frac{500}{V-W} = 2.57$

Apparent Specific Gravity $= \frac{A}{(V-W)-(500-A)} = 2.62$

Absorption Specific Gravity $= \frac{500 - A}{A} \times 100 = 1.42$ percent

A = 493 = weight in grams of oven dry sample in air

V = 450 = volume in milliters of flask

W = 255.2 = weight in grams of water added to flask

B. Amount of Material Finer than No. 200 Sieve in Aggregate

ASTM Designation C117-49

Original dry weight = 497 grams

Weight after washing = 490 grams

Material Finer than No. 200 Sieve $= \frac{497 - 490}{497} \times 100 = 1.40$ percent

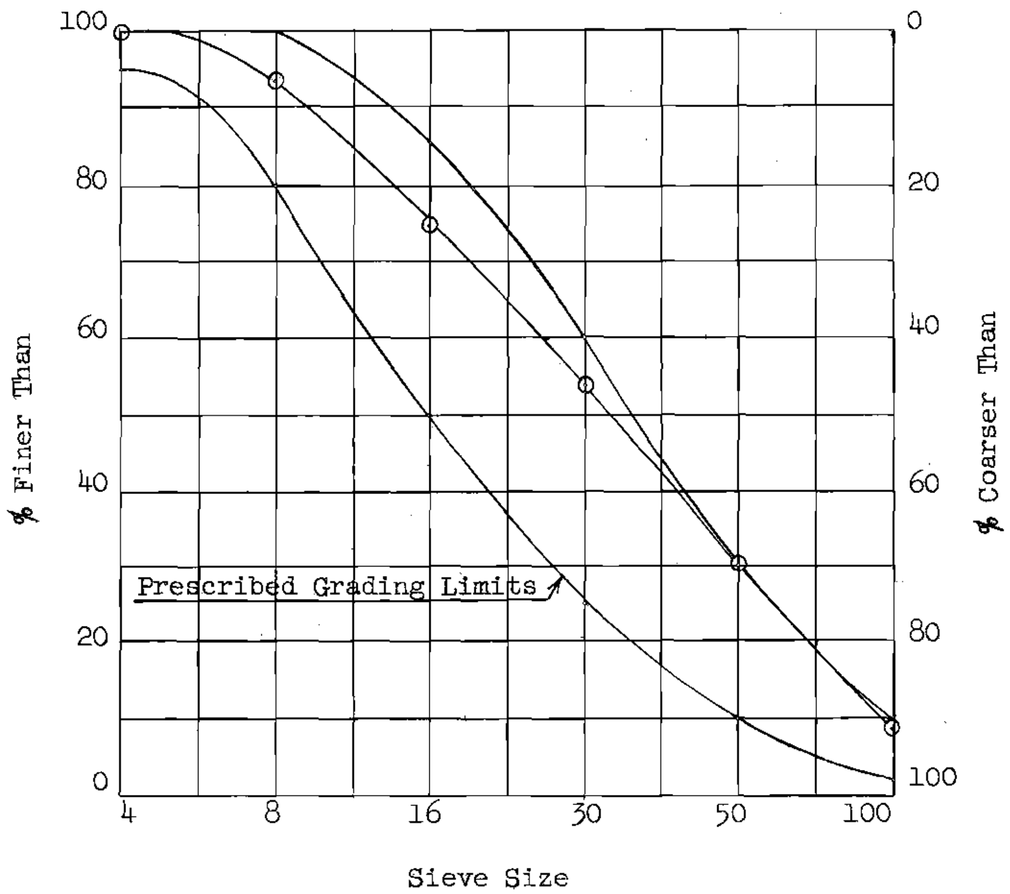
C. Organic Impurities in Sands for Concrete

ASTM Designation C40-48

Type I - No Organic Impurities

D. Sieve Analysis of Fine Aggregate

ASTM Designation C136-46



Sieve Size	Weight Retained	Percent Retained	Cumulative Percent Retained
4	0	0	0
8	25	6.4	6.4
16	73	18.6	25.0
30	83	21.2	46.2
50	93	23.7	69.9
100	84	21.4	91.3
Pan	34	8.7	
			Σ = 239.0

FM = 2.39

Figure 17. Sieve Analysis of Fine Aggregate

E. Soundness of Aggregate (ASTM Designation C88-55T)

Sieve Size Passing	Sieve Size Retained On	Grading of Original Sample Percent	Weight of Test Fraction Before Testing Grams	Percentage Passing Finer Sieve After Test	Weighted Average Corrected Percentage Loss
100	Pan	11.3			
50	100	18.3			
30	50	22.2	100	17.1	3.76
16	30	20.8	100	9.6	1.99
8	16	20.1	100	4.4	0.89
4	8	7.3	100	8.1	0.59
3/8	4	0.0	000	0.0	0.00
Total		100.0	400		7.23

F. Unit Weight of Fine Aggregate (ASTM Designation C29-55T)

Unit Weight of FA = 95.4 pcf

COARSE AGGREGATE ACCEPTANCE TESTS

A. Specific Gravity and Absorption of Coarse Aggregate

ASTM Designation C127-42

Bulk Specific Gravity (dry)	$= \frac{A}{B-C}$	= 2.62
Bulk Specific Gravity (SSD)	$= \frac{B}{B-C}$	= 2.63
Apparent Specific Gravity	$= \frac{A}{A-C}$	= 2.65
Absorption	$= \frac{B-A}{A} \times 100$	= 0.32 percent

A = 3470 = weight in grams of oven dry sample in air

B = 3481 = weight in grams of saturated surface dry sample in air

C = 2156 = weight in grams of saturated sample in water

B. Amount of Material Finer Than No. 200 Sieve in Aggregate

ASTM Designation C117-49

Original dry weight = 2500 grams

Weight after washing = 2490 grams

Material finer than no. 200 sieve $= \frac{2500 - 2490}{2500} \times 100 = 0.40$ percent

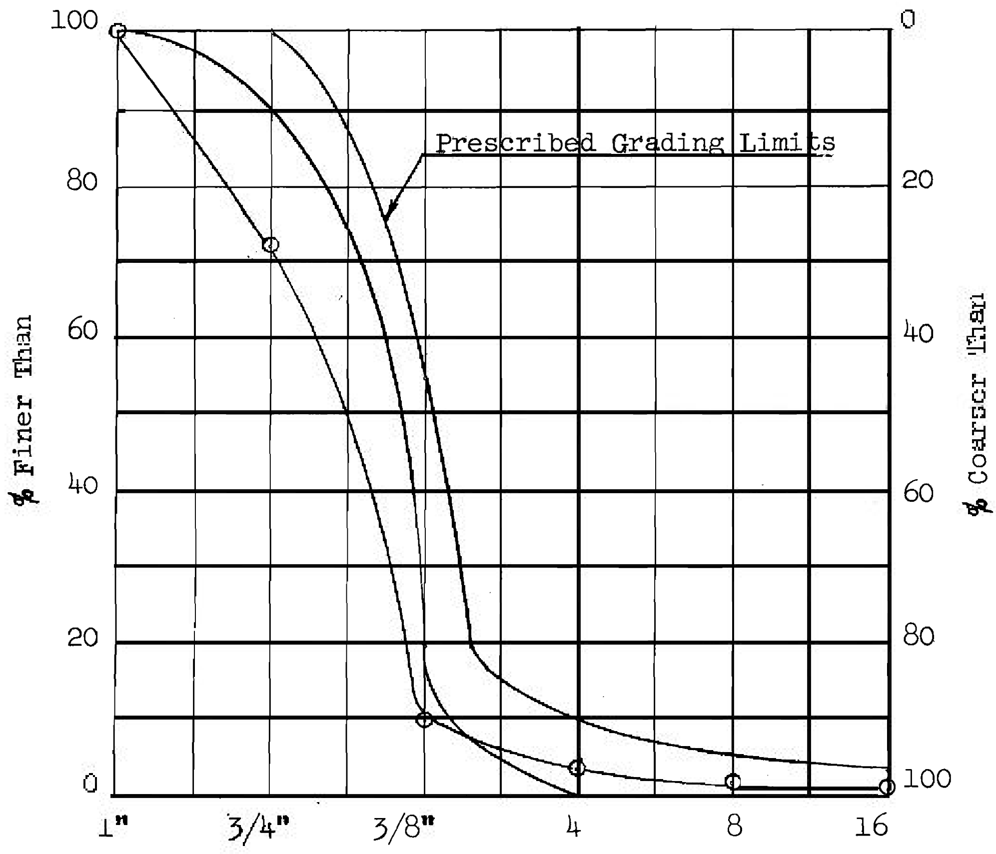
C. Method of Test for Clay Lumps in Natural Aggregates

ASTM Designation C142-55T

No clay lumps present

D. Sieve Analysis of Coarse Aggregate

ASTM Designation C136-46



Sieve Size	Weight Retained	Percent Retained	Cumulative Percent Retained
1-1/2	0	0	0
3-1/2	2686.0	27.80	27.80
3/8	6066.0	62.80	90.60
4	592.5	6.13	96.73
8	217.7	2.25	98.98
16	19.0	0.20	99.10
30	5.5	0.05	99.15
50	3.0	0.03	99.18
100	22.0	0.23	99.41

$\Sigma = 699.95$

FM = 7.00

Figure 18. Sieve Analysis of Coarse Aggregate

E. Abrasions of Coarse Aggregate by the Los Angeles Machine

ASTM Designation C-131-55

$$\text{Percent Wear} = \frac{\text{Weight of Abrased Material Passing No. 12 Sieve}}{\text{Original Weight}}$$

$$\text{Percent Wear} = \frac{2865}{5000} \times 100 = 57.4 \text{ percent}$$

F. Unit Weight of Coarse Aggregate ASTM Designation C29-55T

Unit Weight of CA = 97.6 pcf

G. Unit Weight of Mixed Aggregate ASTM Designation C29-55T

Trial	Volume CA-Ft^3	Weight CA-Lb.	Vol. FA Ft^3	Percent FA by Volume	Unit Weight pcf
1	0.5	48.8	0	0	97.6
2	0.5	48.8	0.1	16.6	107.6
3	0.5	48.8	0.2	28.6	119.2
4	0.5	48.8	0.3	37.5	123.6
5	0.5	48.8	0.4	44.4	123.2
6	0.5	48.8	0.5	50.0	119.0

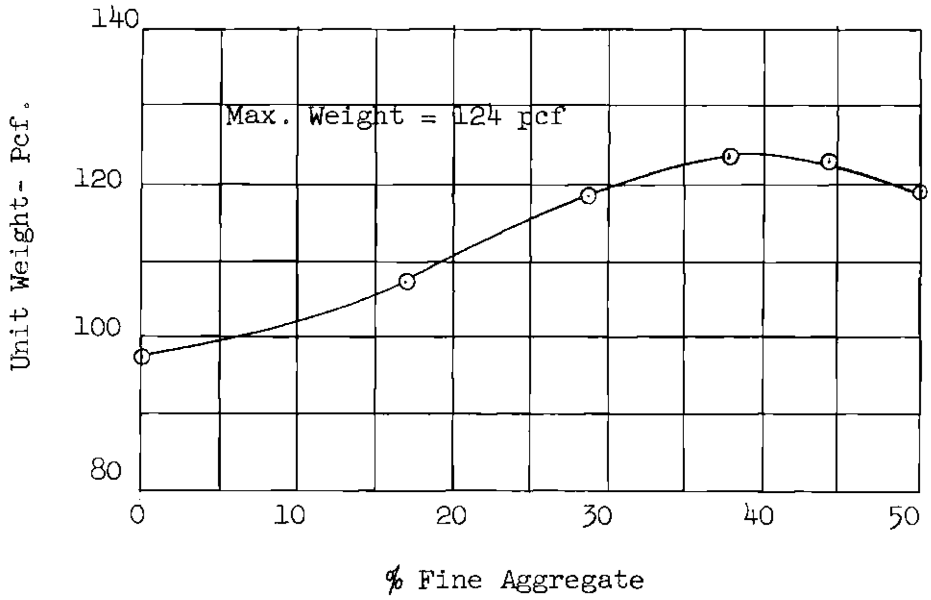


Figure 19. Unit Weight of Mixed Aggregate

Altered Physical Properties of FA and CA for Use in Testing Air Entrained Admixtures for Concrete

ASTM Designation C237-55

A. Sieve Analysis of FA

Sieve Number	Wt. Retained Grams	Percent Passing	Percent Retained	Cumulative Percent Retained
4	0	100	0	0
8	120	88	12	12
16	180	70	18	30
30	230	57	23	53
50	270	30	27	80
100	150	5	15	95
Pan	5	—	5	—
				= 270

FM = 2.70

B. Sieve Analysis of CA

Sieve Number	Wt. Retained Grams	Percent Passing	Percent Retained	Cumulative Percent Retained
1-1/2	0	100	0	0
3/4	500	75	25	25
3/8	1000	25	50	75
4	500	0	25	100
8	0	0	0	100
16	0	0	0	100
30	0	0	0	100
50	0	0	0	100
100	0	0	0	100
				= 700

FM = 7.00

C. Unit Weight of Mixed Aggregate

ASTM Designation C29-55T

Trial	Volume CA-Ft^3	Weight CA-Lb	Vol. FA Ft^3	Percent FA by Volume	Unit Weight Pcf
1	0.5	49.5	0	0	99.0
2	0.5	49.5	0.1	16.6	108.6
3	0.5	49.5	0.2	28.6	115.0
4	0.5	49.5	0.3	37.5	119.2
5	0.5	49.5	0.4	44.4	121.0
6	0.5	49.5	0.5	50.0	119.0
7	0.5	49.5	0.6	54.5	118.0

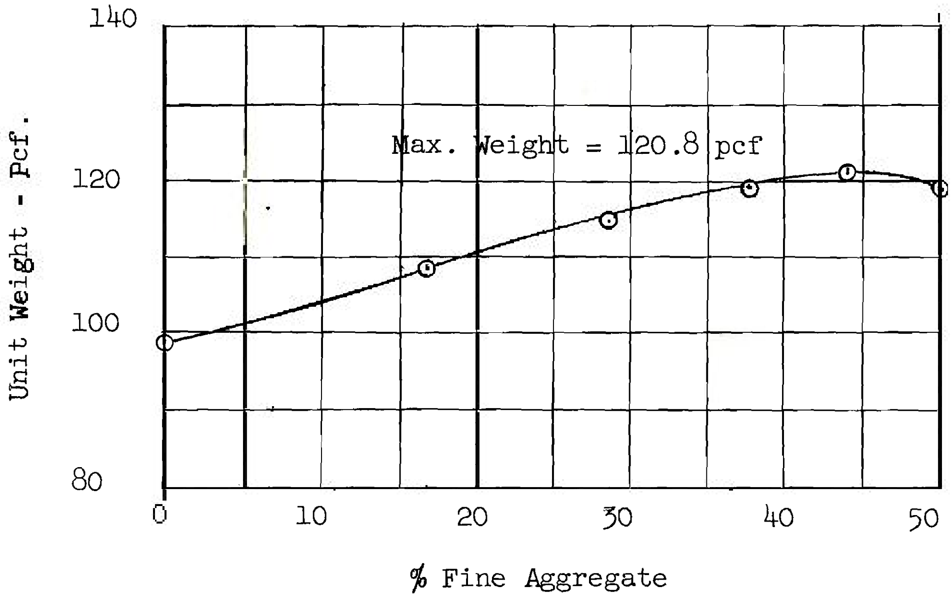


Figure 20. Unit Weight of Mixed Aggregate

Table 20. Cement Acceptance Tests

Summary

Mortar making properties of fine aggregate.

Flow:	Ottawa	=	103	percent
	Lithonia	=	100.5	percent
W/C - Percent:	Ottawa	=	60	percent
	Lithonia	=	59	percent
Normal Consistency		=	27.8	percent
Specific Gravity		=	3.14	percent
Time of Set:	Initial	=	2 hr. 20 min.	
	Final	=	5 hr. 10 min.	

CEMENT ACCEPTANCE TESTS

A. Compressive Strength of Cement Mortars (ASTM Designation C-109-54T)

Flow Test for Ottawa Sand

Water	= 300 grams
Cement	= 500 grams
Sand	= 1375 grams
Average Diameter	= 8.12 inches
Flow = $\frac{4.12}{4.00}$ x 100	= 103 percent
W/C - Percent	= 60 percent

Flow Test for Lithonia Sand

Water	= 295 grams
Cement	= 500 grams
Sand	= 1375 grams
Average Diameter	= 8.02 inches
Flow = $\frac{4.02}{4.00}$ x 100	= 100.5 percent
W/C - Percent	= 59 percent

RESULTS

Age	Lithonia		Average	Ottawa		Average
3	1375	1300	1338	1675	1520	1598
7	1975	2025	2000	2875	2750	2813
28	3550	3750	3650	4560	4830	4695

B. Normal Consistency of Hydraulic Cement Mortars

ASTM Designation C-187-55

Trial	Weight of Portland Cement Grams	Weight of Water Grams	Penetration M.M.
1	500	142	12.25
2	500	140	11.25
3	500	138	8.75
4	500	139	9.50

Percent water for normal consistency $= \frac{139}{500} \times 100 = 27.8$ percent

C. Specific Gravity of Hydraulic Cement-ASTM Designation C-188-44

Weight of cement = 64 grams

Initial reading = 110 ML

Final reading = 130.4 ML

Volume of kerosene displaced = 20.4 ML

$$\text{Specific gravity} = \frac{\text{weight cement}}{\text{displaced volume}} = \frac{64}{20.4} = 3.14$$

D. Tensile Strength of Hydraulic Cement Mortars-ASTM Designation C190-49

Batch Weights

Lithonia			Ottawa		
Cement	400	grams	Cement	400	grams
Sand	1200	grams	Sand	1200	grams
Water	197	grams	Water	197	grams

RESULTS

Age	Lithonia		Average	Ottawa		Average
3	186	200	198	238	260	249
7	260	277	269	375	412	393
28	381	435	408	502	490	496

E. Time of Setting Hydraulic Cement by Gilmore Needles

ASTM Designation C266-51T

Initial Set = 2 hr. 20 min.

Final Set = 5 hr. 10 min.

CONCRETE MIX DESIGN FOR TYPE I PORTLAND CEMENT

Design Specifications:

A pavement slab directly on the ground that is exposed to water in a severe climate where freezing and thawing occurs.

Cement Factor	=	5.5 ± 0.05 sacks per cy.
Water Content	=	38 gal per cy.
Recommend Slump	=	2"-4" (Use 3 ± 1/2")
Percentage of FA for Optimum Density	=	44.5 percent
Percentage of CA for Optimum Density	=	55.5 percent
Bulk Specific Gravity (SSD) FA	=	2.57
Bulk Specific Gravity (SSD) CA	=	2.65
Absorption of Aggregate Before Mixing		
FA	=	1.22 percent
CA	=	0.25 percent

Calculations:

Absolute Volume of Cement	=	$\frac{5.5 \times 94}{3.14 \times 62.4}$	=	2.64 ft^3
Volume of Water	=	38 ÷ 7.50	=	5.06 ft^3
Estimated Free Air at 1.5 percent	=	1.5 x 27	=	0.40 ft^3
Volume of Paste			=	8.10 ft^3
Absolute Volume of Aggregate	=	27 - 8.10	=	18.90 ft^3
Absolute Volume of FA	=	0.445 x 18.90	=	8.40 ft^3
Absolute Volume of CA	=	0.555 x 18.90	=	10.50 ft^3

Table 21. Concrete Mix Proportions

Batch Weights for one Cubic Yard Concrete:

Weight of SSD FA	=	8.40 x 2.57 x 62.4	=	1350 lb
Weight of SSD CA	=	10.50 x 2.65 x 62.4	=	1740 lb
Weight of Cement	=	5.5 x 94	=	517 lb
Weight of Water	=	38 x 8.33	=	316 lb
Weight of one Cubic Yard Concrete			=	3923 lb

Correction for Aggregate Absorption

Weight FA	=	1350 x 0.0122	=	-16.5 lb: 1350 - 16.5	=	1333.5 lb
Weight CA	=	1720 x 0.0025	=	- 4.3 lb: 1740 - 4.3	=	1735.7 lb
Water to be Added			=	20.8 lb: 316 + 20.8	=	336.8 lb
Cement						517.0 lb
One Cubic Yard Cement						3923.0 lb

Table 22. Summary of the Tests Performed

Test	Types of Specimen	Test Ages	No. Spec. Tested	† Condition of Test	Total Specimens Tested
Consistency (slump)	1	1	Min. of 5	22	110
Air Content	1	1	1	22	22
Bleeding	1	1	1	22	22
Unit Weight	1	1	1	22	22
Compressive Strength	1	3	9	22	198
Bond to Steel	2	1	6	11	66
†† Dynamic Modulus	1	3	9	22	198

† Refers to the total amount of admixture concentration including the reference mixes. The admixture concentrations were noted throughout the program as follows:

Admixture A-D: 1 = 0.025 percent by cement weight
2 = 0.05 percent by cement weight
3 = 0.10 percent by cement weight
4 = 0.15 percent by cement weight
5 = 0.25 percent by cement weight

†† Compressive strength specimens used.

S A M P L E   C A L C U L A T I O N S

SAMPLE COMPUTATIONS

The following sample computations show how the information pertaining to mixture 0-0 was derived from the original data. All computations that are self explanatory are omitted.

Volume of Concrete

$$S = \frac{N \times 94 + W_f + W_c + W_w}{W}$$

S = Volume of concrete produced per batch, in cubic feet

N = Number of bags of cement in the batch

94 = Net weight of a bag of cement, in pounds

W_f = Total weight of fine aggregate in batch in condition used, in pounds

W_w = Total weight of mixing water added to batch in pounds

W = Weight of concrete in pounds per cubic foot

$$S = \frac{5.5 \times 94 + 1333.5 + 1735.7 + 336.8}{146.50}$$

$$S = 26.80 \text{ ft}^3$$

Yield

$$Y = \frac{S}{N}$$

Y = Yield of concrete produced per 94 pound sack of cement, in cubic feet

S and N - Previously defined

$$Y = \frac{26.80}{5.50}$$

$$Y = 4.88 \text{ ft}^3 \text{ per bag of cement}$$

Cement Factor

$$N_1 = \frac{27}{Y}$$

N_1 = Number of bags of cement per cubic yard of concrete produced (actual cement factor)

Y = Previously defined

$$N_1 = \frac{27}{4.88}$$

$$N_1 = 5.53$$

Air Content

$$A = \frac{T - W}{T} \times 100$$

A = Air content (percentage of voids) in the concrete

W = Previously defined

T = Theoretical weight of the concrete in pounds per cubic foot, computed on an air free basis. This is computed per batch as:

$$T = \frac{W_1}{V} = \frac{3923}{26.60} = 147.52 \text{ pcf}$$

Where:

W_1 = total weight of component ingredients in the batch in lbs.

V = Total absolute volume of the component ingredients in the batch, in cubic feet.

Bleeding

$$A = \frac{147.52 - 146.50}{147.52} \times 100$$

$$A = 0.69 \text{ percent}$$

Volume of bleeding water per unit of surface area = $\frac{V_1}{A}$

V_1 = Volume of bleeding water, in milliliters, measured during the selected time interval

A = Area of exposed concrete in square centimeters

$$= \frac{28}{50.6} = 0.55$$

Percent bleeding = $\frac{B}{C \times 453.6} \times 100$

B = Total quantity of bleeding water withdrawn from the test specimen, in milliliters

C = Weight of water in the test specimen in pounds = $\frac{W_w}{W_1} \times S_1$

Where:

S_1 = weight of sample, in pounds

W_w and W_1 = previously defined

$C \times 453.6$ = quantity of water in the test specimen, expressed in milliliters.

Sonic Modulus

$$E = CWN^2$$

Where:

W = Weight of specimen in pounds

N = Resonant frequency in cycles per second

C = A factor which depends upon the shape and size of specimen, the mode of vibration and Poisson's ratio.

C may be defined in these general terms:

$$C = \frac{4\pi^2 I^3 T}{gIM^4}$$

or for a cylinder:

$$C = 0.004162 \left(\frac{l}{d}\right)^3 T$$

l = Length of cylinder

d = Diameter of cylinder

T = A value based on the ratio of depth to length of the sample under test; the ratio of longitudinal deformation to the accompanying lateral deformation (Poisson's ratio) and the ratio of average unit shear across a section to the unit shear at the neutral axis.

The following is a solution of T for a 6" x 12" concrete cylinder when Poisson's ratio is assumed to be 1/6.

$$T = 1 + 81.79 \left(\frac{r}{l}\right)^2 - \left[1314 \left(\frac{r}{l}\right)^4 \div 1 + 81.09 \left(\frac{r}{l}\right)^2\right]$$

r = radius of gyration = d/4 for a cylinder

l = length of cylinder

$$T = 1 + 81.79 \times \left(\frac{1.5}{12}\right)^2 - \left[1314 \times \left(\frac{1.5}{12}\right)^4 \div 1 + 81.09 \left(\frac{1.5}{12}\right)^2\right]$$

$$T = 1 + 1.265 - \frac{0.318}{1 + 1.265}$$

$$T = 2.125 \text{ or } 2.1$$

Thus:

$$C = 0.0041632 \times \left(\frac{12}{6}\right)^3 \times 2.1$$

$$C = 0.06994176 \text{ sec}^2 \text{ per inch}$$

or $C = 0.01165 \text{ sec}^2 \text{ per inch}^2$

$$E = 0.01165 \times 29.0 \times (29.8)^2$$

$$E = 3.007$$

or $E = 3.01$ psi

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